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MOTION PICTURE AND TELEVISION ENGINEERS

High-Speed Photography in Europe

Microsecond Still Camera

Vision Benefits Through Stereo

Visual Monitor for Magnetic Tape

Westrex Film Editer

Nonintermittent Photomagnetic Editor

Automatic Film Splicer

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The Development of High-Speed Photography in Europe

By HUBERT SCHARDIN

The main features of European high-speed photographic instrumentation are described, including cameras using stationary film, those with intermittently or continuously moving film, and those incorporating the film drum. Methods of lighting high-speed photography with various spark arrangements are discussed.

Since it is hardly possible in a brief review to present a total picture of the development of high-speed photography in Europe, an attempt is made here to select data showing the general trend in the field during the past sixty years.

MECHANICAL METHODS

Cameras With Fixed Film Strip

It is a little-known fact that as early as 1892 the Prussian Armaments Testing Commission (Preussische Artillerie Prüfungskommission) constructed a camera in which the film was stationary, with a speed of 1000 frames/sec, the exposure time of each frame being 10^{-4} sec.

Figure 1 shows schematically the principle of this camera, which was certainly influenced by the work of Muybridge in California. For this early venture in high-speed photography, 12 cameras were set along the quarter-arc of a circle. Exposure was accomplished by a slit in a rotating disk with a diameter of 230 cm and a speed of 20 rps. The velocity of the slit was therefore the astonishing one for that day of 145 m/sec.

At that time the focal length of lenses was considerably greater than is used today, so that the distance between two cameras was 14.5 cm, resulting in a repe-

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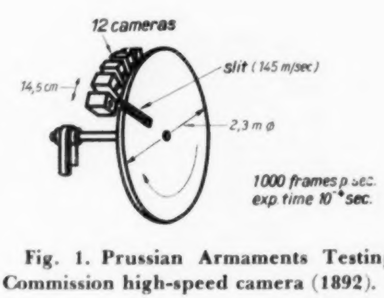

Fig. 1. Prussian Armaments Testing Commission high-speed camera (1892).

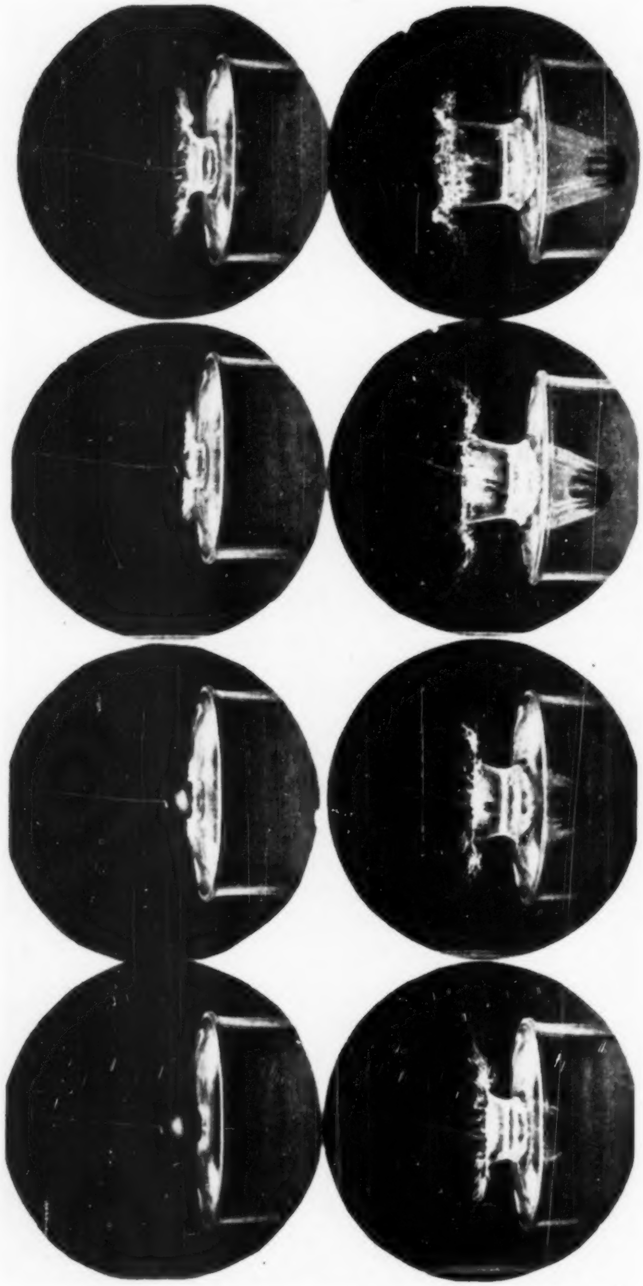

Fig. 2. Selection from a sequence taken with the Bull camera (3000 frames/sec) showing the entry of a ball into water.

tition rate of 1000 frames/sec. With modern short focal-length lenses, the same arrangement would produce a correspondingly higher framing rate. Lucien Bull (a colleague of Marey, the famous French pioneer in cinematography) built a similar camera in Paris in 1933. It was capable of taking 50 pictures on a single 13 × 18 cm plate at a speed of 3000 frames/sec. Figure 2, showing in successive stages the entry of a falling ball into water, is an example of the work of this camera.

About 1930, the firm of Askania in Berlin constructed a camera with 12 lenses; however, there were 13 slits in the disk, so that exposure was complete after a 30° rotation. The framing rate was 15,000 frames/sec.

The repetition rate increases as the lens diameters decrease. Therefore, with a 1-mm slit, operating at 100 m/sec, the exposure time per frame would be 10^{-5} sec, provided each exposure starts at the end of the preceding one. Under these conditions it should be possible to attain a rate of 100,000 frames/sec.

This has been achieved in the English Marley camera (Fig. 3), which has 59 lenses, and mirrors through which 59 images are reflected on a film strip.[1] The effective aperture is $f/27$; therefore only very bright objects may be photographed successfully. There are 16 slits in the rotating disk, requiring a rotation of 22.5° for exposure of all 59 frames.

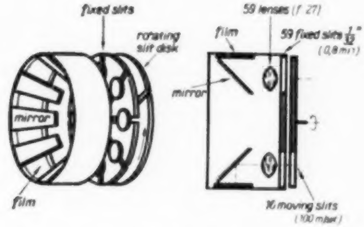

Fig. 3. The Marley camera (100,000 frames/sec) (1949).

Cameras With Rotating Light Beam

The next development is a simple one. The revolving mechanical slit disk is replaced by a rotating light beam, the speed of which can be, of course, increased considerably over that of the disk. The American Miller and Bowen cameras apply this principle, and it has also been applied in Europe.

First should be mentioned a design of the German firm of Rheinmetall (1944). This camera (Fig. 4) has an annular ring with 50 fixed lenses and a fixed film strip. The frames are exposed in succession by means of a rotating mirror. This method requires that the image on the film be stationary during exposure; therefore the intermediate image must be on the mirror. Because of the war, Rheinmetall was unable to complete the development of this camera, but the work has been carried on by the British Royal Naval Scientific Service.[2]

Another application of this principle is that of Bartels (Fig. 5). He substitutes

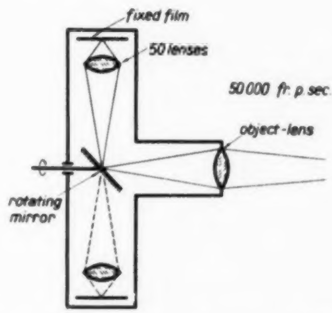

Fig. 4. The Rheinmetall camera (1944).

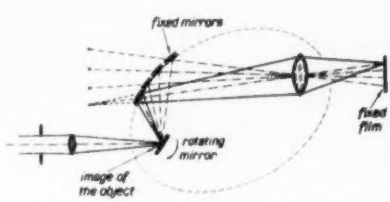

Fig. 5. The Bartels camera (1949).

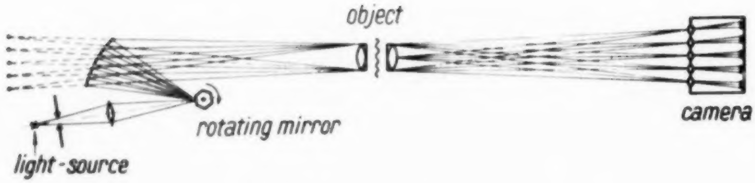

Fig. 6. Mechanical light control of the multiple-spark camera (Schardin, 1949).

fixed mirrors for the required number of lenses and uses only one object lens. Again an intermediate image is formed on the rotating mirror. Bartels' camera is very economical, since it can be set up with ease using the normal equipment of a research laboratory.

It is often very useful, particularly when schlieren illumination is required, to use a multi-lens system for mechanical light control. The resulting system behaves like a multiple-spark camera, but uses only one light source (Fig. 6). This may be regarded as the continuation of the multiple-spark principle into the region of lower framing rates.

Cameras With Intermittently Moving Film

All the cameras so far mentioned have the disadvantage of producing only a limited number of frames. The first remedy is the intermittent displacement of the film when exposure of a given segment has been completed; i.e. during exposure, and as long as the shutter is open, the film is at rest. It is interesting to note that Marey, in Paris in 1885, obtained 110 normal-sized frames/sec in his photographic gun. Even today it is impossible to achieve much more than double this rate, since the velocity of intermittently moved film cannot normally exceed 5 m/sec. Figure 7 shows an original Marey series of a dog in motion. The European Vinten, Debrie and Askania cameras produce about 250 frames/sec on 35mm film. It is perhaps surprising that intermittent cameras attaining the possible maximum for 16mm and 8mm film do not yet exist. It is interesting in this respect to mention the development by the Swedish Armament Department of an intermittent-motion camera with a speed of more than 1,000 frames/sec. The intermittent film motion is achieved by a film drive consisting in part of two splined rubber rollers.

Cameras With Continuously Moving Film

The first important camera using the principle of optical compensation and taking pictures on continuously moving film is certainly the "Zeitlupe" of Lehmann, built in 1916 by Ernemann and in 1928 by Zeiss Ikon. The use of the principle of compensation with a rotating polygonal mirror is schematically shown in Fig. 8.

It is probably unnecessary to describe this well-known camera in detail, since its use is now so widespread. It was first used for ballistics studies during World War I. At that time it had a speed of only 500 frames/sec. Rumpff proposed in 1916 to increase this rate by using three cameras in parallel connection, with an adequate phase shift of exposure times. Such a triple camera was subsequently developed, and others similar to it followed.

It is worth pointing out that the quality of the picture sequence produced by several cameras in this way is inferior to that produced by a single camera with a correspondingly higher framing rate. If the exposure time of one frame is greater

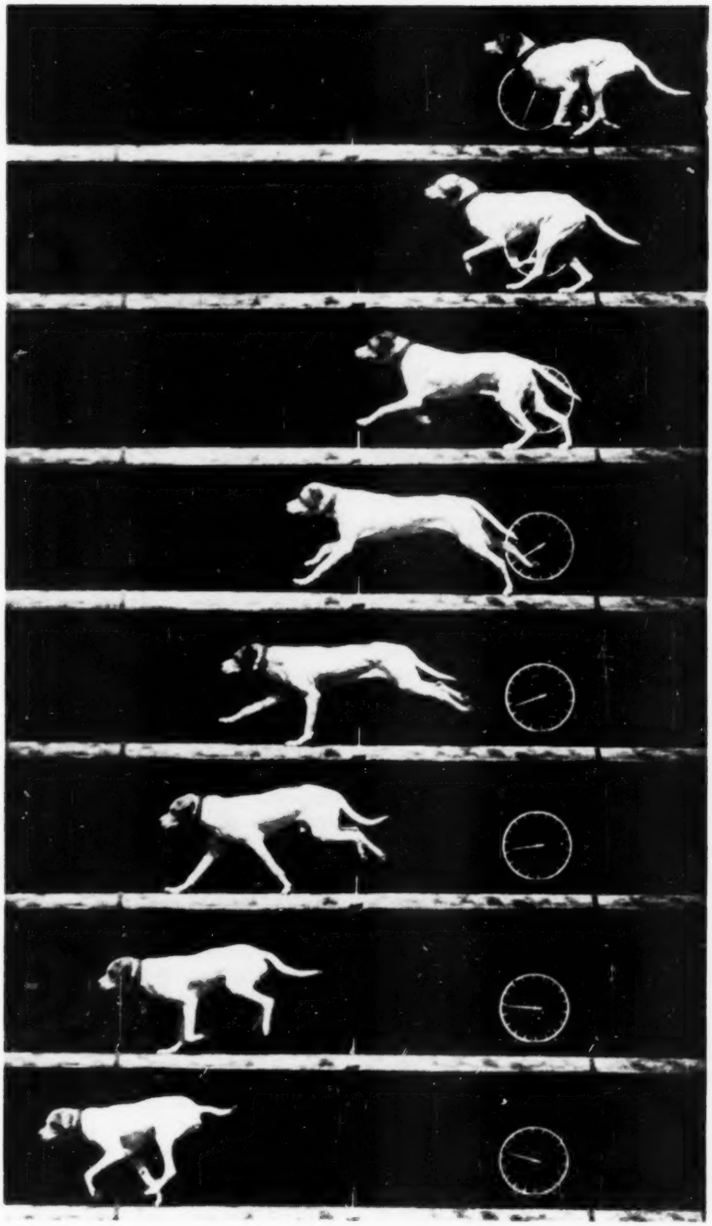

Fig. 7. Part of a sequence taken by Marey (120 frames/sec).

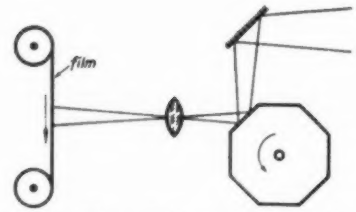

Fig. 8. The "Zeitlupe" camera (Lehmann, 250–500 frames/sec; Zeiss Ikon, 1500 frames/sec).

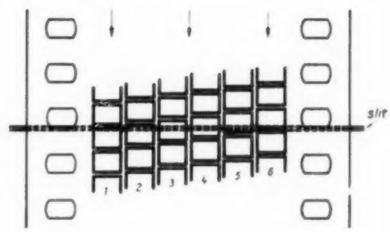

Fig. 9. Frame-division method of time resolution.

than the reciprocal of frame frequency, the blur caused by motion in the object is magnified and impairs clarity. In practice, three cameras in parallel connection have a time resolution only 37% higher than that of one of them operating alone.

Optical compensation can also be effected in other ways. In a number of cameras it is achieved with rotating prisms or lenses.

A camera employing an octahedral prism is the Rotax designed by Askania.[3] Though it produces only 600 frames/sec on normal film, it is worthy of mention since its images have fairly good resolution and its weight is only 13 lb. It can be hand-held during operation.

Optical compensation by means of rotating lenses has been applied since 1926 chiefly by Thun, whose cameras have been commercially produced by Askania and A.E.G. In France there are two similar cameras manufactured by Merlin-Gerin-Debuit of Grenoble. One is designed for 16mm film and has a speed of 3000 frames/sec; the other, for 8mm film achieves 6000 frames/sec.

An advantage of the A.E.G. camera is the fact that its lens disk is interchangeable with a slit disk. Moreover, each frame can be divided into a great number of small frames, up to 80, each of them only 1.8 × 3 mm in size. Thus an increase in exposure rate up to 80,000 frames/sec is achieved.

As early as 1936, Thun suggested the possibility of achieving practically continuous time resolution. As is seen in Fig. 9, a narrow slit traverses six individual frames, each of which is slightly displaced longitudinally (on the time axis). The slit therefore simultaneously exposes a different segment of each of the six frames. Were we to view these frames, not much time resolution would be evident, since the exposure times of the frames overlap considerably. However, by reconstituting into one picture all the segments exposed at the same instant, very good time resolution can be achieved.

Decreasing the size of the slit and increasing the number of frame divisions will bring about still better time resolution, but with considerable sacrifice in image quality. Therefore, in using this method it is important to fix optimal conditions for both these factors.

Drum Cameras

If a great number of frames is not required, one strip of film may be fixed on a rotating drum and the complexities of moving film avoided.

The first drum camera with optical compensation by mirrors in practical use is probably Rumpff's model of about 1928. The frame was 120 mm broad by 7 mm high, the speed 5000 frames/sec, and the length of film allowed for 50 frames.

The MGD firm of Grenoble, France, has manufactured a drum camera with rotating lenses, the arrangement of

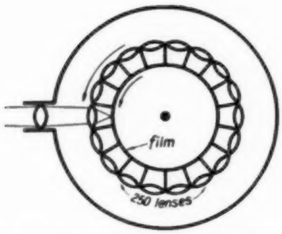

Fig. 10. The Merlin-Gerin-Debuit camera.

which is worth study (Fig. 10).[4] The film drum and the lens ring are one compact piece, rotating together. Optical compensation is provided by the difference between the tangential velocities of lenses and film. Three rings of lenses are set parallel i.. the camera, each ring taking 250 pictures. The speed is 33,000 frames/sec for each ring and would be 100,000 frames/sec for the three rings were it not for the fact that the exposure time for one frame is greater than the time difference between two parallel frames — a consideration which greatly reduces effective speed.

ELECTRICAL METHODS

The second group of photographic instrumentation tools is based on the electrical discharge of a condenser. To study a rapid phenomenon, it is not always necessary to use a high picture repetition rate; one sharp picture with sufficient detail sometimes gives excellent information.

Ernst Mach, about 1880, first made use of the electrical spark discharged from a condenser to photograph high-speed phenomena such as shock waves, explosions and moving projectiles. C. Cranz continued this work, achieving bright, brief sparks which made his shots, even by today's standards, models of fine still-picture technique (Figs. 11a and 11b).

The early simple form of electrical discharge in air is still used for photographic lighting, particularly when brief flashes are required. But much has been done in the last twenty years to increase the optical effectiveness of this method. Two factors have been important in this development: (1) the substitution of krypton or xenon for air; and (2) the prolongation of the discharge channel. Using these two factors, Harold E. Edgerton in America devised the first electrical flashlamps.

In our German laboratory, during the war, the guided-spark principle was used to prolong the discharge path. It becomes possible, for example, to increase the length of a 40,000-v spark from 15 mm (sphere) to 800 mm, and to increase brightness by the factor 10. An energy of 800 wattsec produced a guided spark in air which illuminated a surface 4 × 4 m sufficiently to take pictures with a Kerr-cell camera, the exposure time being 1 μsec. These guided-spark tubes, filled with xenon, are now produced under the name "Defatron" by the French Central Armaments Laboratory. Major Naslin has described this instrument in detail.[5]

Cameras Using Pulsed Spark Gaps

There are two methods of illuminating a motion-picture subject with sparks: (1) by flashing a series of sparks between the same electrodes; and (2) by the use of a multiple-spark gap. The first method encounters some difficulty such as image separation and the removal of ionization in the spark gap.

The simplest method of controlling the spark is a mechanical one. Lucien Bull in 1904 constructed the first spark camera, using this means (Fig. 12). With a rotating switch and an inductor he produced 2000 sparks/sec; 50 frames of normal size were taken on a rotating drum. The energy of each spark was, of course, not very great.

In 1905 Kranzfelder and Schwinning successively discharged 10 condensers through a single spark gap by means of a

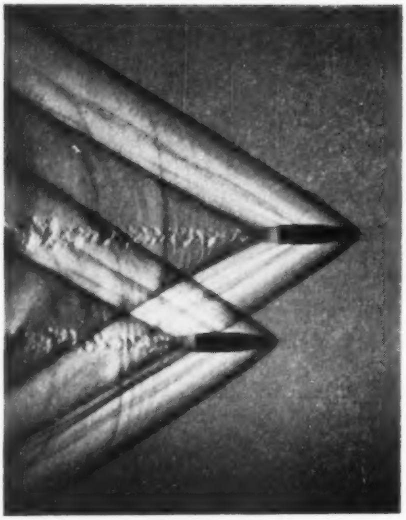

Fig. 11a. Schlieren exposure of two projectiles fired simultaneously.

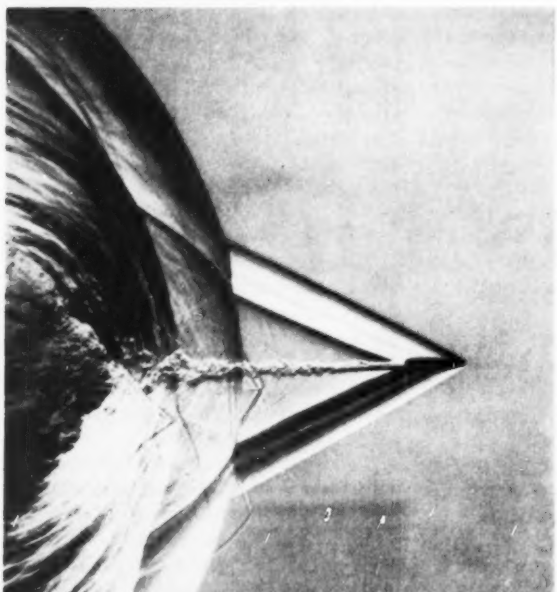

Fig. 11b. Projectile after exit of the nozzle shock wave.

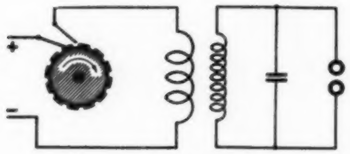

Fig. 12. The Lucien Bull spark camera (1904).

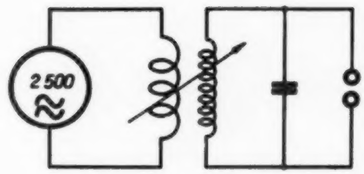

Fig. 13. The Cranz "Ballistics Cinematograph" (1909).

rotating switch. This principle is sometimes made use of today, as in the French LCA camera, which operates at a speed of up to 10,000 frames/sec.

Cranz's "Ballistics Cinematograph" of 1909 (Fig. 13) applied yet another principle. Here an oscillator feeds a pulse network. The condenser discharges at each half cycle at a frequency of 2,500 cycles/sec. The speed of the camera is 5000 or 10,000 frames/sec, using a rotating drum. Cranz used this camera often and successfully for the study of ballistics problems.

Another way of producing a series of sparks is through the alternating charge and discharge of a condenser (Fig. 14).

In 1912 Schatte used a resistance for spark control, attaining 50,000 sparks/-sec. In the same year Glatzel applied the principle of spark telegraphy with a result of 100,000 sparks/sec.

Yet a better method is the use of an inductance to control condenser-discharge (Toepler), since this involves no loss of energy. The operation of this arrangement has been calculated in recent years by Schering, Vollrath and Neubert.

Repeated flashing of a single spark requires the separation of frames on the film, which makes high speed difficult to achieve (Fig. 15).

A film laid on the outside of a drum can achieve a velocity of 120 m/sec, and it is possible for a film with frames 10 mm high to attain 12,000 frames/sec. If the same film is laid on the inside of the drum, up to 25,000 frames/sec may be reached. A rotating mirror in the center of a fixed drum could produce a maximum rate of about 170,000 frames/-sec, but in this case a satisfactory flash of sufficient energy in the single spark gap is difficult to achieve, and the finite

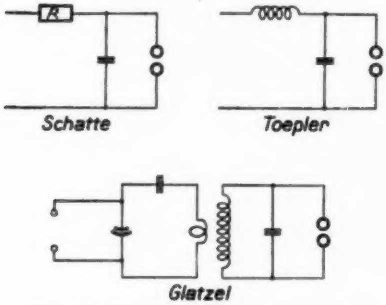

Fig. 14. Methods of spark control.

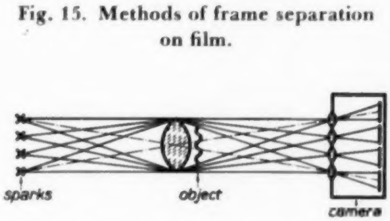

Fig. 15. Methods of frame separation on film.

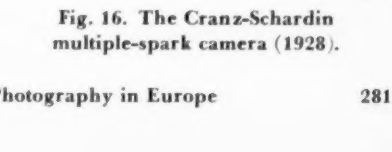

Fig. 16. The Cranz-Schardin multiple-spark camera (1928).

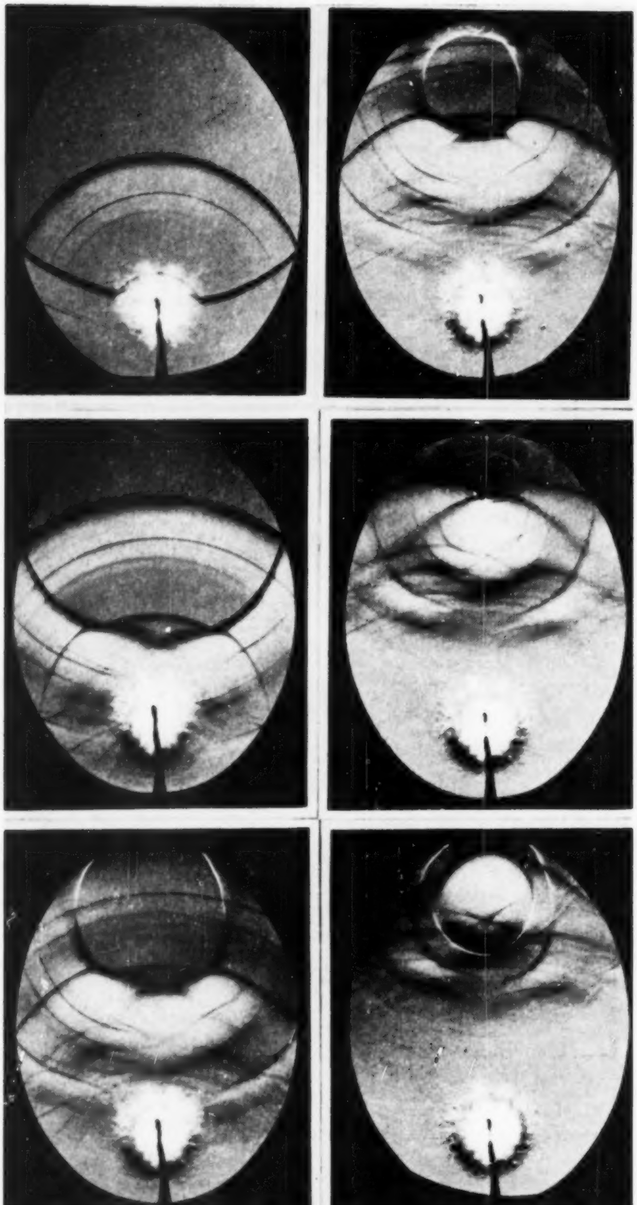

Fig. 17. Selection from a sequence taken with the Cranz-Schardin multiple-spark camera showing the reflection of a shock wave in an ellipsoid (30,000 frames/sec).

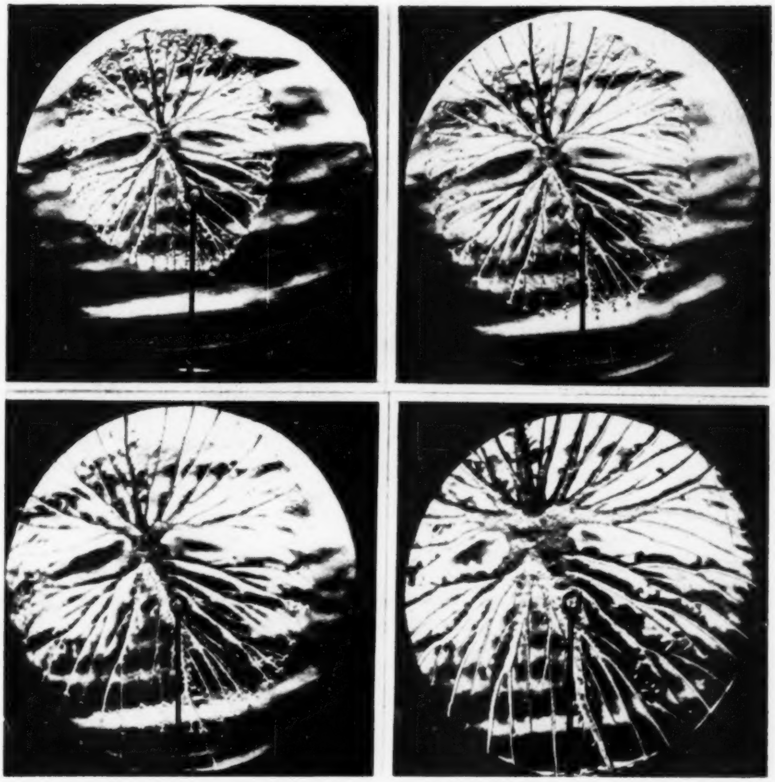

Fig. 18. Selection of sequence taken with Cranz-Schardin multiple-spark camera showing fracture of thin membrane used in a shock tube (80,000 frames/sec).

duration of the spark ($\sim 10^{-6}$ sec) will cause blurring.

The Multiple-Spark Camera

For high-speed photography therefore, the multiple-spark camera (Fig. 16) is preferred. Some of its advantages are as follows:

1. Exposure rates of 10^6 frames/sec and more present no difficulties.
2. The picture size does not depend on the exposure rate and can be large enough to show any data needed.
3. No moving parts are necessary, except perhaps for time measurement.

The shortcomings of the multiple-spark camera are, chiefly:

1. The limited number of frames which can be taken.
2. The presence of parallax.
3. The impossibility of photographing self-luminous phenomena.

In spite of these limitations, however, the multiple-spark camera is capable of such extraordinarily exact photography as to make it a most useful tool for photographic instrumentation. The time difference between two sparks can be measured with an accuracy of more than 10^{-7} sec, and the precision in location

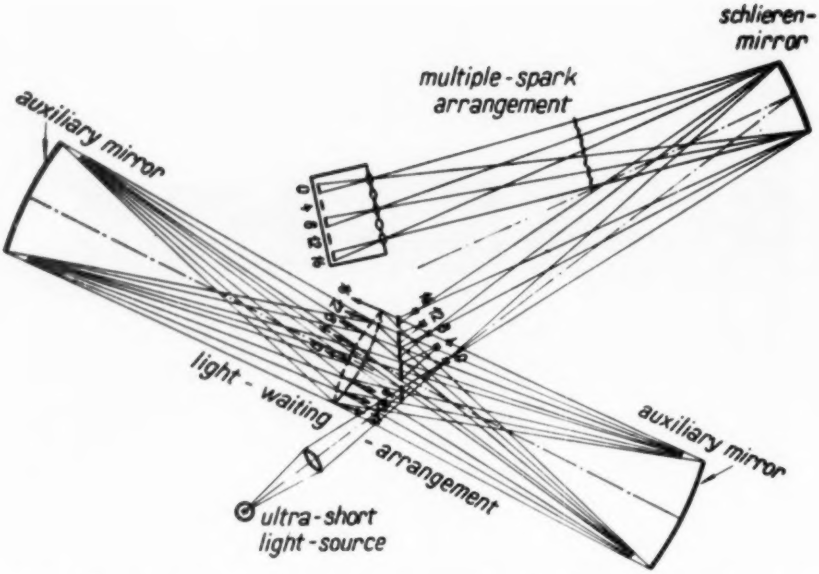

Fig. 19. Optical arrangement of ultra high-speed motion-picture camera based on Cranz-Schardin system using velocity of light (1949).

of a point in the object is about 0.1 mm. The error caused by parallax may be avoided by photographing a calibration grid on the same plate. Some idea of the applications of the multiple-spark camera is given in Figs. 17 and 18.

The usual electrical method of triggering successive sparks will produce a maximum of 10^7 frames/sec. If it is possible to flash only *one* spark of sufficient brightness, and shorter than 10^{-7} sec, the optical arrangement shown in Fig. 19 will produce a higher exposure rate.

Before entering the camera, the light of the spark is reflected several times by two auxiliary mirrors. After each two reflections comes the next light beam, the time delay being dependent on the velocity of light and the focal length of the auxiliary mirrors. An exposure rate of about 10^9 frames/sec appears to be possible.

Kerr-Cell Cinematography

The separation of pictures in the multiple-spark camera is based on the fact that an image of the multiple sparks is formed in the corresponding lenses.

This principle does not function (a) in daylight, (b) if the object is self-luminous, or (c) if the object is to be studied in reflected light.

If any of these conditions must be met, the Muybridge equipment, as described above, is used, but with Kerr-cell shutters. In our laboratory, during the war, we used eight Kerr cells, of which two were used jointly to take stereoscopic pictures. The Kerr cells had a 37-mm aperture and were controlled by 40,000 v. When objects were to be photographed in daylight or by reflected light a guided spark was flashed to supply the light necessary for an ex-

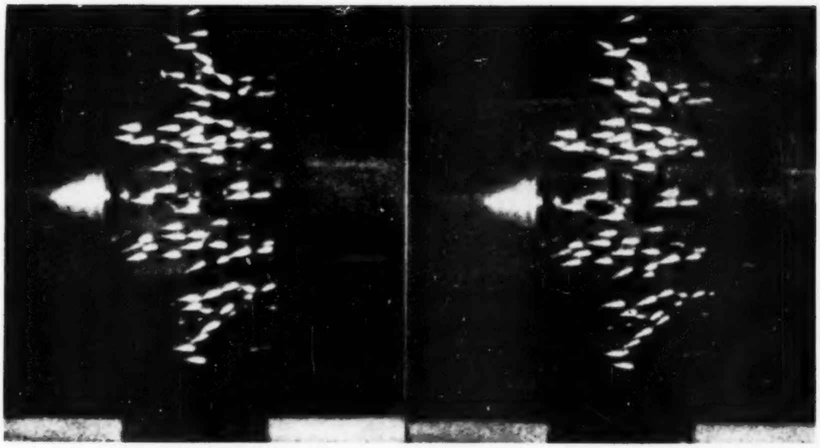

Fig. 20. Stereoscopic Kerr-cell exposure of a bursting shell filled with small projectiles.

posure time of about 1 μsec. In each case two Kerr cells formed an electrical unit; the time difference between the opening of two successive shutters could be regulated from 1 μsec on up. Figure 20 is an example of the results achieved by this process.

Image-Converter Photography

Another possible constituent of the electrooptical shutter is the image converter, known in the field of television. In collaboration with the A.E.G. research laboratory, E. Fünfer of the Laboratoire de Recherches, developed (1940) a convenient converter tube arrangement. Photographs thus produced were somewhat inferior to those made using the Kerr-cell technique, but further research, such as that now being made by Courtney-Pratt in England, may bring about improvement.

In a review such as this it is impossible to mention every aspect of European high-speed photographic development; among other matters, mention of methods of triggering or of the use of X-ray flash sources has necessarily been omitted. It is hoped that this brief summary will have given American engineers at least a broad general idea of European high-speed camera achievements.

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A Microsecond Still Camera

By HAROLD E. EDGERTON and KENNETH J. GERMESHAUSEN

A shutter with an effective open time of about 1 μsec is described which was specially designed to photograph high explosives during detonation. Precision adjustment of the exposure instant by a time-delay circuit triggered by the explosion light is used for synchronization. Optical systems of focal lengths of 6 in. to 6 ft have been employed. Examples are given of pentolite and TNT explosions.

EXPERIMENTS with high explosives using a previously described magnetooptic shutter* indicated that a shorter exposure time would be advantageous in studying high-velocity shock waves and flame fronts. Accordingly the equipment herein described was designed with every effort to obtain a simple, rugged field instrument with a 1-μsec shutter open time.

The Magnetooptic Shutter

The complete camera assembly as used for field work is shown in Fig. 1. The microsecond shutter is located in the square-shaped aluminum casting. On the back of this casting is a mounting position to accept a 4 × 5 in. Eastman view camera, although almost any camera can be used with slight modification of the base. Provision is made on the back side of the magnetooptic shutter to fit the lens ring of a Wollensak shutter containing a 163-mm focal-length lens. The "X" synchronizing contacts on the Wollensak shutter enable the operator to fire his explosive charge without a long open time which might fog the film due to light leakage through the closed polarizers. An image of a subject illuminated by direct sunlight will be dimly exposed in 10 sec with fast film even if the polarizers are accurately crossed.

The magnetooptic shutter described in this paper was the result of a redesign of the previously designed 4-μsec model in the following ways:

1. The aperture was reduced from 1 in. in diameter to 1 cm.

2. A single pair of Polaroids instead of two crossed pairs was used.

Presented on May 1, 1953, at the Society's Convention at Los Angeles by Harold E. Edgerton (who read the paper) and Kenneth J. Germeshausen, Edgerton, Germeshausen & Grier, Inc., 160 Brookline Ave., Boston, Mass.
(This paper was received March 27, 1953.)

* Harold E. Edgerton and Charles W. Wyckoff, "A rapid action shutter with no moving parts," *Jour. SMPTE, 56:* 398–406, Apr. 1951.

3. The capacity was decreased from 4 to 0.3 μf.

4. A spark gap and capacitor assembly was designed to eliminate as much circuit inductance as possible.

The main capacitor circuit consists of ten 0.03-μf capacitors in parallel, arranged to have a low interconnecting inductance. Figure 2 shows the assembly in the casting that encloses the capacitors and the magnetooptic shutter together with the gaps and associated pulse transformers.

Fig. 1. One microsecond shutter in square case in front of a 4 × 5 in. view camera. Note photoelectric cell on side of shutter for triggering from the light pulses from explosions. The box at the bottom includes power supplies and control circuits.

Figure 3 shows a cross section of the magnetooptic shutter as well as details of the electrical circuit that pulses the 5-turn coil around the extra-dense flint-glass magnetooptic element. The glass is constructed of Bausch & Lomb Type EDF-4 annealed glass in the form of a cylinder 1 cm in diameter and 2 cm long. The two-gap circuit is used to excite the shutter coil for a half-cycle as has been described in the reference given above. These two gaps are shown in the diagram, Fig. 3, together with the pulse transformers that trigger them.

The "A" pulse coil initiates the discharge of the 0.3-μf capacitor into the coil around the glass element. The "B" pulse coil triggers the quench airgap which short-circuits the main capacitor into a damping resistor after a half-cycle of operation. In this manner, the energy in the circuit is removed so that the capacitance, C, and inductance, L, will not oscillate.

The light-time transmission of the shutter under normal operating conditions is shown in Fig. 4, as sketched from oscillographic observations. The 100% light transmission refers to the transmission with the polarizers (Type HN23) in a parallel position which corresponds to a density of about 1. The transient open-transmission density is close to that of the uncrossed condition since the rotation is about 90°.

Electrical cables connect the camera and shutter portion to the power supply and control unit, which are in the box shown on the floor in Fig. 1. Details of the delay and trigger circuits in the control unit are given in Fig. 5. The trigger portion of the circuit is usually a photoelectric tube, marked 929 on Fig. 5, although a "make" circuit or a positive voltage pulse is equally effective. The

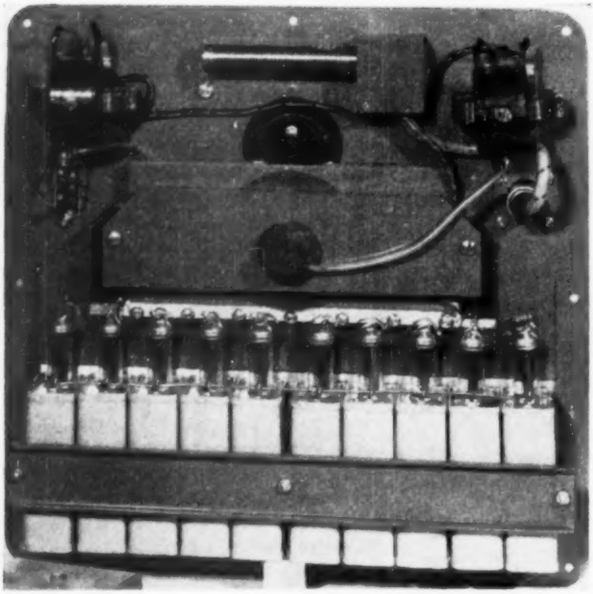


Fig. 2. Inside view of the magnetooptic shutter showing capacitors, spark gaps, trigger transformers, etc.

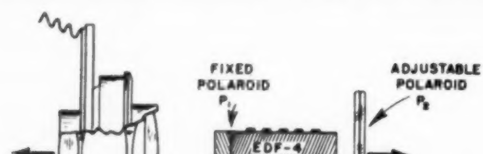


Fig. 3. Cross-sectional view of magnetooptic shutter and driving circuit.

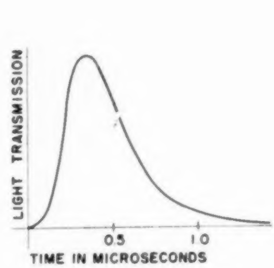


Fig. 4. Transmission of the magnetooptic shutter as a function of time.

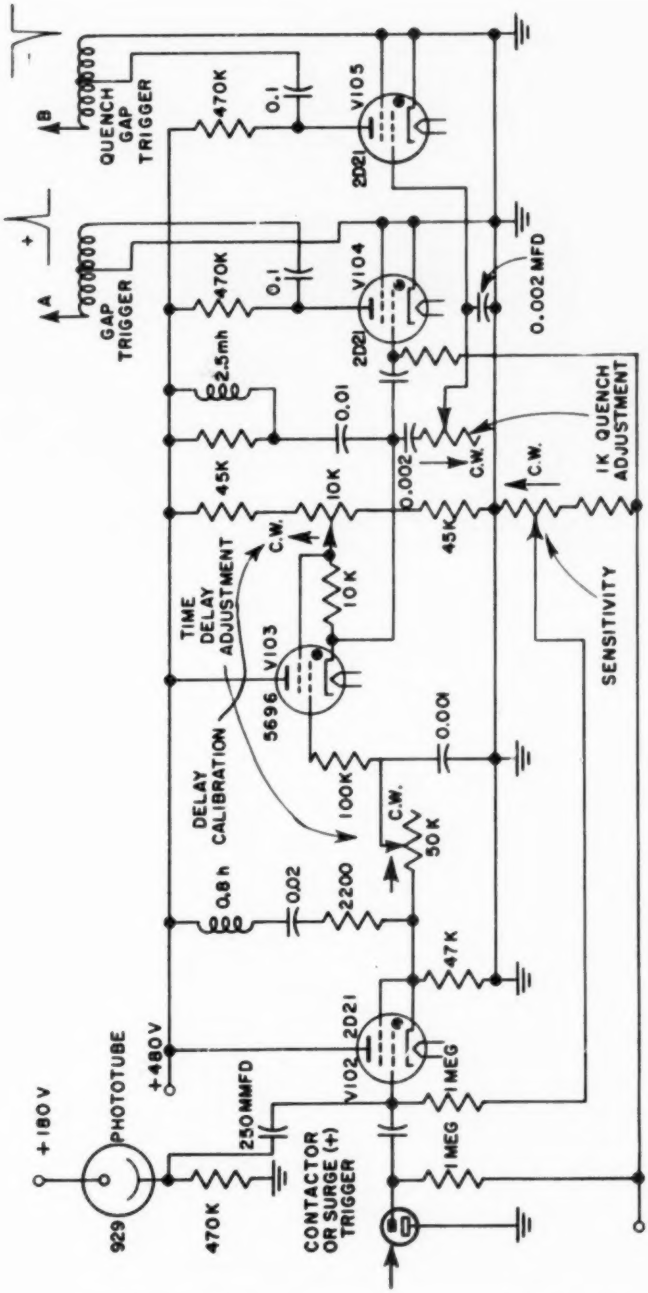


Fig. 5. Control and time-delay circuits for magnetooptic shutter.

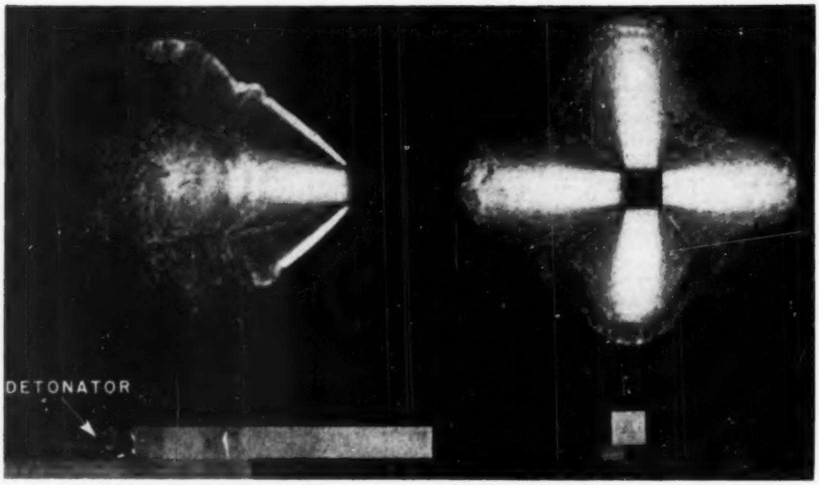


Fig. 6. Composite photos. Below: a square stick of Pentolite $\frac{3}{4}$ in. on a side and 6 in. long. Note fractured portion repaired with scotch tape. Above left: a 1-μsec. exposure with an EG&G Type 2208-0 Rapatronic camera timed 15 μsec following initiation. Note ripple in shock flame front corresponding to fracture. Also note that luminosity does not start at the detonation front on the stick. Above right: end view of a similar explosion. (Photos taken at the Ballistic Research Laboratory, Aberdeen Proving Ground.)

flash of light from a subject illuminates the photocell creating a voltage pulse which trips the thyratron (V102) and the delay RC network. A dial on the unit controls the resistance (50 K variable) of the RC coupling portion of the circuit. The pick-off thyratron (V103) triggers after the time delay as determined by the pick-off voltage on the adjustable resistor (10K). The coil "A" exciting thyratron, V104, triggers instantaneously with V103 followed in about $\frac{3}{4}$ μsec by V105 which triggers the quench gap and coil "B."

Examples showing $\frac{3}{4}$-in. square sticks of pentolite as they explode are shown in Fig. 6. These photographs were made with the camera of Fig. 1 with the time delay set at 15 μsec. The explosions were in a heavy-walled concrete chamber at the Terminal Ballistic Laboratory at Aberdeen, Md., where a thick glass window of the shatter-proof type permitted the camera to be placed close to the explosions without danger.

An interesting and often useful effect results when the quenching gap is prevented from firing. One method of accomplishing this is to remove the thyratron V105 from its socket. If the quench gap does not operate, then the current through the shutter coil will oscillate at the natural frequency of the circuit consisting of the capacitance, C, and coil inductance, L, as given by

$$f = 1/2\pi\sqrt{LC} \text{ cycles/sec}$$

The shutter does not depend upon the polarity of the current, therefore the shutter will open twice per cycle. The frequency is about one million times per second. Figure 7 shows the same subject as Fig. 6 when photographed with an undamped shutter. Note the interesting

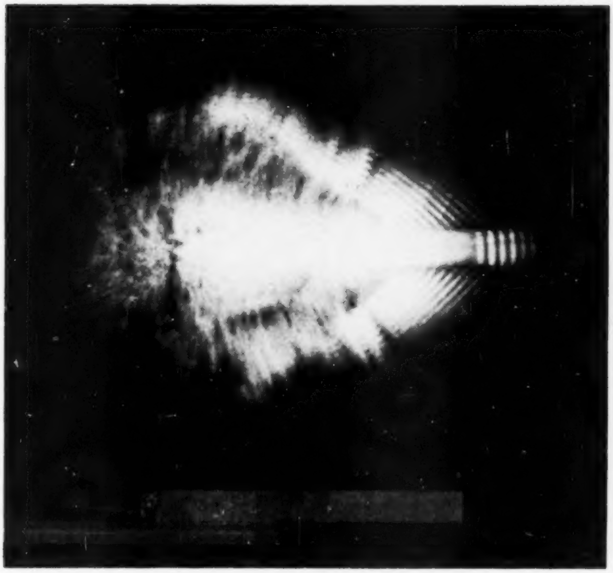


Fig. 7. Below: two 3-in. sections of $\frac{3}{4}$-in. square Pentolite sticks taped together with scotch tape. Above: same subject photographed by EG&G Type 2208-0 Rapatronic with shutter oscillating 1 mc. (Tube V105 has been removed so that the quench gap does not fire.) Note high velocity of products from the end of the explosion.

end effects when the explosion reaches the end of the explosive.

Teletronic Assembly

The shutter previously described has been used also with two telescope types of mirror optical systems of long focal length. In this way large explosions can be studied photographically from a safe distance.

One of the telescopes was a Wollensak 40-in. Mirrortel. The primary image was formed in the magnetooptic glass element and subsequently enlarged twice on a 35mm Exakta Camera. The reflex features of this camera were used for initial alignment and focus. A "before" photograph was taken immediately prior to detonation to show size and any unusual features.

A photomultiplier tube was used to trigger the magnetooptic shutter for the distance photographs (approximately 750 ft). A tube with small holes at both ends was used to exclude most of the daylight that would saturate the tube.

The other telescope was a Newtonian system of about 6-ft focal length. The primary image was again brought out at the front of the telescope by means of a small right-angle mirror into the magnetooptic shutter. As before, the image was then enlarged twice on a 35mm Exakta Camera.

Photographs of one of the telescope cameras and examples taken with it at the Aberdeen Proving Ground are given in accompanying figures.

Often a series of accurately timed photographs is desired when an explosive

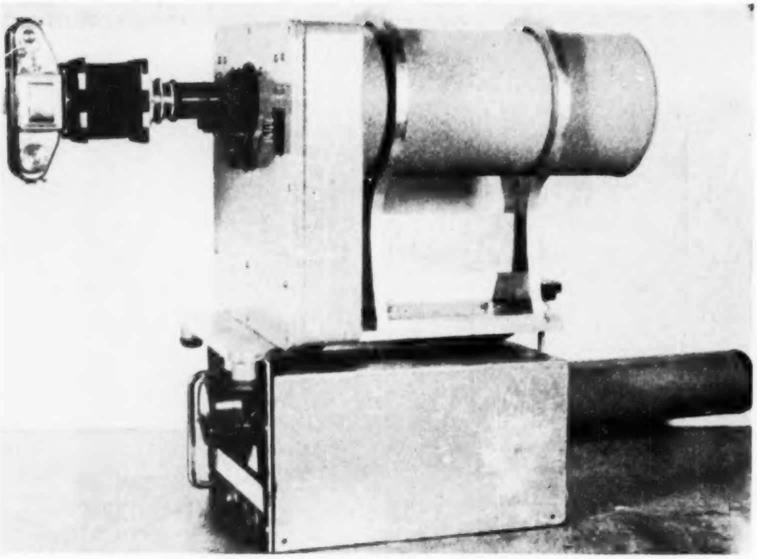


Fig. 8. Wollensak Mirrortel (40-in.) mounted on a 1-μsec shutter with an Exakta Camera. Below is photomultiplier trigger.

event is studied. To accomplish this, a series of several magnetooptic cameras can be used, each with a different time delay. A sequence of pictures like these can be compared to a motion-picture record, except that the rate may be irregular as set on the time-delay dials and the pictures can be taken with different lenses. Furthermore, very few motion-picture cameras can operate at cycling rates or individual exposure times corresponding to those obtainable from the magnetooptic shutter. The focal lengths of the lenses can be changed to cover the subject properly at the required instants of time. Stereoscopic photographs of explosions can also be taken by using two cameras that have the same delay but with different positions of the cameras in space.

The 1-μsec magnetooptic shutter with photoelectric triggering and time-delay circuits provides a convenient new field research tool for the explosive engineer and scientist. Especially with long focal-length optics, excellent resolution of explosions in space can be obtained at a safe distance and without the necessity of elaborate protection. Shutter synchronization by means of light from the explosion is most convenient since no electrical or mechanical connection to the explosion is required.

Discussion

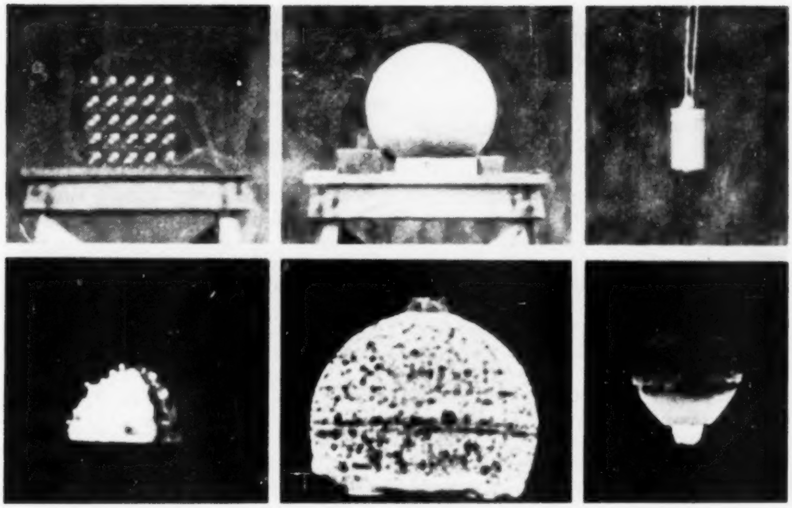
Anon: Has any attempt been made to synchronize the optical shutter technique with moving film?

Dr. Edgerton: No.

Anon: It sounds as though it would be a very potent idea.

Dr. Edgerton: Compared to the Kerr cell our exposure is very long. As we saw the other day, it is possible to get very sharp definition with the Kerr cell, while the duration of the magnetooptic shutter is quite a bit longer.

Anon: One of the major advantages that a d-c driven motion-picture camera has to



25 blocks of TNT (above) and (below) detonation. **65-lb pentolite sphere (above) and (below) 30 μsec after detonation.** **Cylindrical charge (above) and (below) after detonation.**

Fig. 9. Teletronic photographs taken with Wollensak 40-in. Mirrortel and 1-μsec shutter shown in Fig. 8, at a distance of about 750 ft (Ballistic Research Laboratory, Aberdeen Proving Ground).

offer all the way along is that it permits higher and higher camera speeds resulting in shorter and shorter exposures.

Dr. Edgerton: Well, we get shorter exposures another way. The Rapatronic camera is simple. The 110-v a-c power supply weighs only 35 lb and the camera weighs less. When a picture interval in milliseconds is required with a total of 50 pictures, just get 50 of these, line them up, set the lights, and all 50 of them will go. If you want 100 of them, get 100. What difference does it make?

With this approach to the problem, you get as many pictures as you need. Every effort has been made to get the simple, reliable field tool; not a complicated thing with jets, turbines and other fancy affairs. This 1-μsec shutter has been designed in an effort to get an everyday working tool, just like your automobile or jacknife. For explosion engineers it seems to me it's a natural. Up to now there was no tool except slit-type cameras to measure the velocity, so they have been living on a one-dimensional world. All the data are merely recorded on a slit to get velocity of the detonation. The Rapatronic camera records a two-dimensional world, with an excellent, clear image.

Anon: Did you take the before-and-after pictures through the same optics, and, if so, did this require moving the optical shutter out of the path?

Dr. Edgerton: Yes, with the earlier model used at that time. It's very important to get a complete still picture of the subject for reference. We used to do it by shining stroboscopic light on the subject and then triggering the shutter. On the current model one simply rotates the lever and the optical shutter is open, permitting focus on a ground glass.

In fact, you use the mechanical shutter just like you would in normal photography. The only difficulty you have is that in the "open" position two polarizers are parallel and produce a density of approximately one, and experience dictates the excess exposure required. Then you have to re-

member, of course, to close the optical shutter. That is like pulling your dark slide; it is very important.

Lawrence F. Brunswick (Colorvision Inc.): Is it possible that the apparent lack of luminance at the point of explosion in these photographs is actually a result of considerable over-exposure and consequent reversal?

Dr. Edgerton: Mr. Sultanoff, would you answer that?

Morton Sultanoff (Aberdeen Proving Ground): We have experienced this condition, and I would say quite positively that it is not the result of reversal from over-exposure. Much more work on this matter was published recently in open literature by the Bureau of Mines. I think this was in their October-December "Physics and Chemistry of Explosive Phenomena" progress report. Their explanation is based on theory which predicts that a rarefaction wave moves in from the surface and causes the pressure in the detonation front near the surface to be reduced in bare charges. This makes the detonation velocity lower, and consequently results in a front that curves back at the surface. The appearance of the shock not joining the detonation front at the surface is explained in the Bureau of Mines report as the result of that curvature. If you are interested you might contact them — the group under Dr. Bernard Lewis — for more information.

Wallace Allan (Naval Ordnance Test Station, Inyokern, Calif.): Does the field of view of the shutter have any advantage over the Kerr cell? The Kerr cell is limited to a rather small field of view.

Dr. Edgerton: No, these pictures are taken with a standard 4 × 5 camera with fixed lens. The image size on the film is about an inch.

Mr. Allan: That is a fairly small angle, if you desire as much as 60–70°.

Dr. Edgerton: The shutter will accept 70°. A 6⅜-in. lens and 4 × 5 plate can record a maximum of 50°. It is the object that must then be big enough.

Anon: Could your system find application, perhaps, in photographing the burning of kerosene?

Dr. Edgerton: There are two functions of this shutter: One is to keep the light out for exposure. You might want to use one of these shutters to eliminate light. That is like the example of the firecracker that I showed you. The other is when you photograph the light from the explosion. Now I doubt whether burning kerosene has a high enough light level to record during this relatively short exposure time. This shutter is a new thing, and we are still looking for new uses for it. There aren't too many people who shoot off explosions.

Benefits to Vision Through Stereoscopic Films

By REUEL A. SHERMAN

This paper emphasizes the need for good engineering in the production of stereo films to insure conformity with normal patterns of psycho-physiological functions of binocular vision. It describes the impact of stereoscopic motion pictures on the ophthalmic world and outlines some of the therapeutic benefits from viewing stereoscopic motion pictures. An orderly program is needed to inform the public of the potent stimulation to good binocular vision which results from viewing properly produced and projected stereoscopic motion pictures.

Let us look in at a Main Street theater in our average American city. The last row of seats is 75 ft and the front row is 22 ft from the screen. John and Jane Doe have come to see the new stereoscopic feature. They have taken the average seat 50 ft from the screen.

John is a skilled mechanic, an average American citizen, 35 years of age, in good health. He has good vision, eyes that are skillful. They function smoothly, effortlessly and instantly. The glasses he wears help to give him this efficiency.

Jane is the same age, and a good housewife. She wears no glasses. She has been told by her doctor that she should wear a prescription but she doesn't. Her trouble is not in her ability to see clearly because her acuity in each eye is excellent, but for other reasons she is visually uncomfortable.

The feature starts. John and Jane put on their polarizing spectacles and settle back comfortably for an evening of thrilling entertainment. Before the show is over, John is having trouble. His ordinarily skillful, efficient, binocular vision is causing him obvious discomfort. On the other hand, Jane who usually experiences difficulty is enjoying the performance with greater freedom from symptoms of visual disturbance than she ordinarily has in her daily occupations.

The cause of this apparent incongruity is in the vertical displacement of the two images. By not keeping the two images in frame, the projectionist has put an unnecessary burden on 98% of the patrons in the theater. By so doing he

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has made it easier for the remaining 2% including Jane. The screen image from the right-eye projector is not framed vertically with the screen image from the left-eye projector. Jane has a right hyperphoria. The visual axis of her right eye tends to be above that of her left eye. The improperly projected picture automatically compensates for her visual impediment.

On the other hand, the 2% of the patrons in the theater who have a *left hyperphoria* are penalized even more than John who represents the 96% with correct vertical phorias.

John's eyes were not harmed even though he experienced discomfort from the abnormal visual gymnastics which they performed in maintaining fusion of the improperly aligned frames. No physiological damage could have resulted. Nevertheless the discomfort was unwarranted.

Vertical alignment of the frames and synchronization of the two projected pictures must be exact. Had the right-eye and left-eye frames been precisely and correctly aligned, Jane probably would have had considerable discomfort while 96% of the customers, including John whose eyes were in normal balance vertically, would have been comfortable and happy. This would have re-emphasized to Jane her need for professional, ophthalmic services for her own general well-being both in and out of the theater. The stereoscopic pictures could have been the stimulus needed for her to put her visual house in order.

The illumination from the two projectors should be matched as equally as possible. If relative illumination between right- and left-eye images varies more than 12%, some individuals may find that interference with their binocular vision results.

A small number, approximately 2% of the population, have better and more efficient binocular vision when the right-eye visual image is more luminous than the left-eye visual image. Another 2% have more efficient binocular vision when the left-eye image is more luminous than the right-eye image.

Slight differences between the visibility of right- and left-eye stereoscopic pictures do not seem to bother the average individual. But when the 2% whose eyes perform better with less luminosity in the right eye get more of it by unequally balanced illumination in the projectors, the tendency is to aggravate a latent condition which interferes with binocular efficiency.[1,2,3]

The projection lenses should be matched. It is recommended that variances between the right- and left-eye lenses do not exceed plus or minus 0.5% in focal length. For another example, let us consider a second couple sitting in the Main Street theater at a distance of 50 ft from the screen. He has excellent visual acuity in each eye, good binocular functional ability, while she has difficulty with any visual task that requires or induces sustained visual concentration such as an automobile trip, watching television, attending the conventional movies, or sitting through a lecture or sermon.

Again, viewing the stereoscopic motion picture brings comfort and satisfaction to her, while to him it brings a visual disturbance. Again the projectionist in this particular theater has something wrong with his equipment. The projection lenses are not matched. The right eye projected image is larger than the left eye projected image. In her case there was a disparity in the size of her retinal images which has not been corrected through ophthalmic care. The improperly matched projection lenses favored her condition so that she experienced a false sense of comfort while he who was not accustomed to disparity in size of images was irritated. This failure to match the lenses had benefited 1% of the audience and penalized 99%.

It seems that we have picked on the

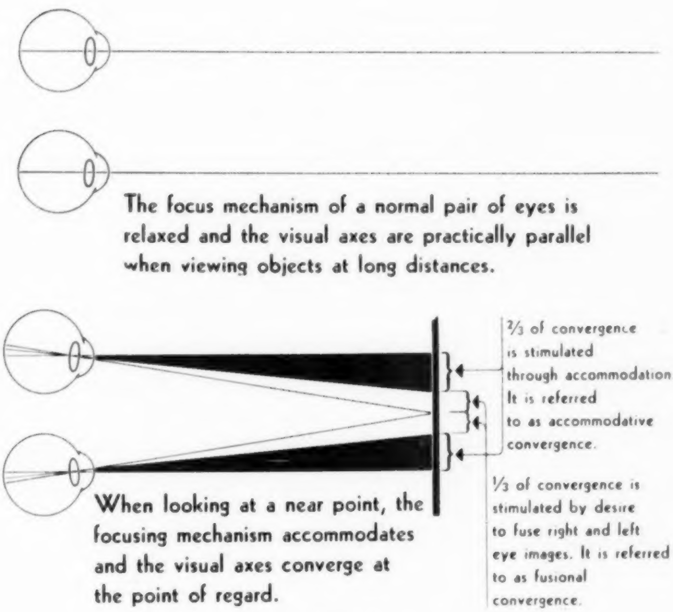


Figure 1

projectionist in the Main Street theater as having committed mechanical errors. Surely we can conceive of no combination of all such circumstances happening in any one theater during the exhibition of any one feature. Nevertheless, one of them can easily happen if conditions are not checked carefully.

The penalizing of producers, theater owners and the public through lack of attention to these details is unfortunate. A small percentage of patrons with visual difficulties will be favored by such errors, while the majority with normal binocular vision will be disturbed. These conditions should be reversed so that those with normal binocular vision will be stimulated to even greater enjoyment of the feature, while those who should do something about their visual performance will receive the incentive to act in their own behalf.

Of the customers who view stereoscopic motion pictures 85 to 88% can enjoy them without feeling visual tension or discomfort, providing consideration is given to those projection problems which we have covered, and providing the films are properly produced. The relationship between two visual functions, accommodation (focus) and convergence, probably is one of the important factors to consider in the production process. An understanding of the inter-relationship between these two visual functions may help in outlining certain rules. The accommodative-convergence relationship in a pair of human eyes will be considered only as it relates to the production of stereoscopic pictures and as the viewing of the pictures influences these functions.

Figure 1 illustrates the relationship between the focusing of a pair of eyes and their converging toward and on the point of regard. As the normal pair of eyes changes fixation from a "long shot" to a "close-up," or from a far point to

a near point, two demands must be met to obtain single, clear binocular vision:

1. The focusing action of the eyes must adjust so that a sharp image will appear on each retina.

2. The 12 extra-ocular muscles must coordinate to turn each eye so that it will look precisely at the object of regard.

To a large extent binocular seeing is a learned function.[19] Some of us learn to see with skill and efficiency; others do it clumsily, haltingly, and inaccurately. In the average individual these complex adjustments are made instantly and with effortless facility. Through the conditioning of reflexes or other psychophysiological functions, a stimulation to convergence induces accommodation and inversely a stimulation to accommodation induces convergence.

Two-thirds of the amount of convergence required for fixation ordinarily is induced by the effort to accommodate. In Fig. 1 the shaded area represents this amount, which usually is referred to as accommodative convergence. The remaining third usually is referred to as fusional convergence. Fusional convergence is a reflex action induced by the mental desire for a single image. It is achieved by the eyes turning so that the image of regard is on corresponding points of each retina. Most of us with binocular vision demonstrate varying degrees of this accommodative convergence relationship with the great majority grouped around the limits indicated by this figure.[21]

We have emphasized the importance of accommodation in stimulating convergence but conversely the effort to converge also stimulates accommodation. This accommodation convergence which works both ways has been established through habit and learning. Those of us with effortless, skillful binocular coordination will converge when a stimulus is applied and still maintain our accommodation at the point where it is required for sharp focus. Others have little latitude between their accommodation and convergence. They have what might be referred to as a "tight hook-up" between the two functions. They cannot relax one function easily while stimulation of the other is maintained.

Such individuals usually have the ingredients for very efficient seeing, but interfering reflexes in their accommodative-convergence habits cause functional opposition often associated with discomfort. Their convergence may be overstimulated by their accommodation. In other cases there is little or no interfunctional stimulation. Their accommodative effort does not induce convergence, nor does their convergence effort induce accommodation.

These abnormal situations are problems for the skilled ophthalmic practitioner. The accommodative-convergence relationship, however, has an engineering connotation in the production and projection of stereoscopic motion pictures.

More often than not, those who lack flexibility between the functions of accommodation and convergence have excellent acuity with each eye. Judging their visual abilities solely by the sharpness of their sight, such individuals are lulled into a false sense of security — into a feeling that such excellent acuity precludes any need for professional services. Such subjects probably will be identified as needing professional attention by discomfort resulting from their viewing of stereoscopic motion pictures.

Figure 2 illustrates the impact of viewing stereoscopic motion pictures on the accommodative-convergence functions. It also illustrates the importance of considering these factors in producing films. In binocular performance, our accommodation gives us our sharp clear images by which we identify the object of regard; whereas convergence enables the two eyes to fixate or center upon the object of regard, so that single vision is maintained. In stereoscopic motion pictures our ac-

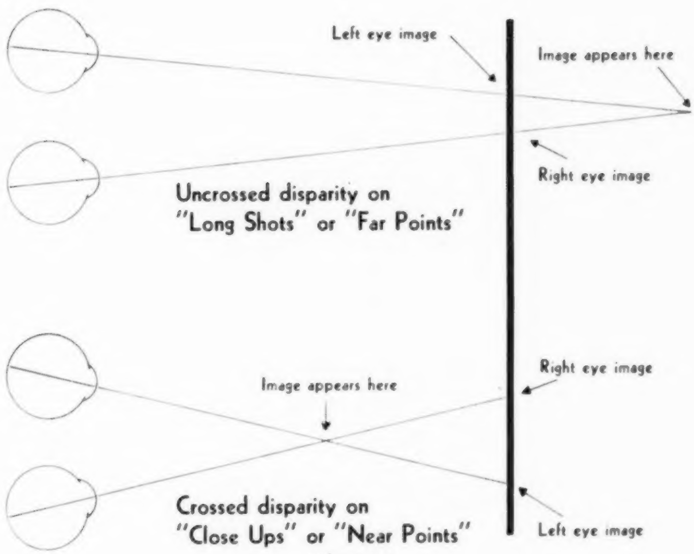


Figure 2

commodation gives us our sharp clear images. Our convergence localizes the objects in space either in front of or behind the screen (stereo windows). Efficient and effortless viewing demands new and independent responses from the two functions. Accommodation (or focus) must be maintained constantly on the surface of the screen if the individual is to see a sharp image. Convergence must act with independent flexibility so that each eye will point to its own image without the aid of accommodation, or conversely without interfering with the maintenance of it on the surface of the screen (stereo window).

In other words, those people who converge skillfully, independently of their focus, get a stimulating calisthenic experience from viewing properly made stereoscopic motion pictures. Such practice teaches them to converge when the stimulus to convergence is presented and to accommodate when the stimulus to accommodation is presented. Viewing stereoscopic pictures provides an excellent exercise in developing flexibility between the two functions and precision in each one. Fortunately such individuals are by far in the majority. On the other hand, those who have a "tight hook-up" between their accommodation and convergence should profit greatly from ophthalmic attention and from the visual "setting up exercises" provided by the same pictures.

The optometrist or ophthalmologist whose help is sought as a result of discomfort experienced from viewing properly made stereoscopic motion pictures will make careful tests of the refractive condition of each eye, and of the functional pattern of seeing. His prescription may include simple or complex prescription lenses different for each eye, specifically designed for the condition of the individual. Such lenses may serve several very useful purposes. They may balance the acuity of the two eyes. They may also stabilize the accommodative-convergence relationship.

In addition, the professional man may prescribe a series of training procedures to teach each eye to function efficiently

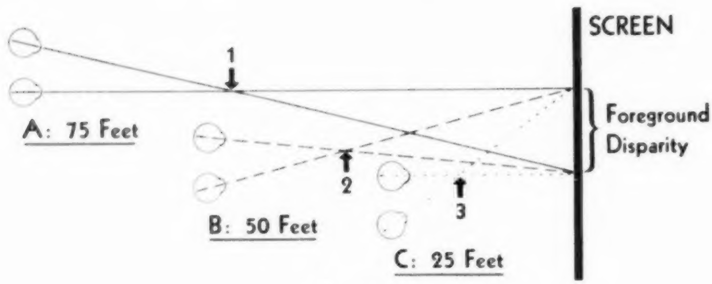


Figure 3

by itself. When this is accomplished he may then continue the training so as to teach the two eyes to function together effortlessly and skillfully. A part of this training procedure may well be the recommendation to see stereoscopic motion pictures periodically — once a day or once a week for example. It may be that he will recommend to his patient that he choose a seat in the front row for the first day and, as he improves in visual performance, that he move progressively back a row or two of seats, so that eventually he can sit in the rear row and view the full feature with comfort and satisfaction. For other patients he may reverse the prescription, suggesting that they start in the back row and periodically move closer to the screen.

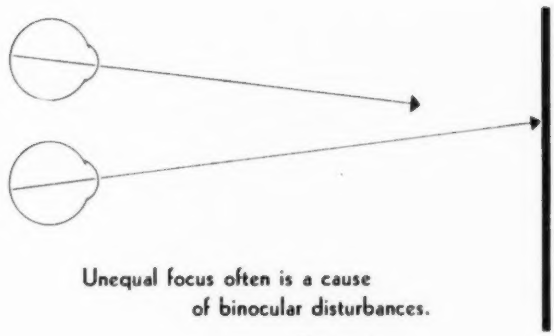
The disparity of the projected images of close-ups should not exceed 1/20 of the distance between the screen and the closest spectators. For example it should not exceed 12 in. in theaters where patrons will be as close as 20 ft from the screen. A foreground (crossed) disparity of 12 in., viewed from a distance of 20 ft will mean that the individual will need to converge as though looking at a point approximately 4 ft in front of him while still maintaining his focus on the surface of the screen 20 ft away.[20] The average person will be able to do this with ease provided such stimulation is momentary and infrequent. It would be difficult for most of us to maintain this convergence over a long period of time.

The close-up disparity can be increased or decreased in direct ratio to the distance of the nearest seats to the screen. As a further example, if the nearest point of observation from the screen is to be 30 ft, the foreground disparity can be as high as 18 in. and still remain within the range of tolerance of the average individual.

The background (uncrossed) disparity should not be more than $2\frac{1}{2}$ in. in pictures produced for entertainment. This holds true regardless of the size of the screen or of the distance from the screen to the audience. As the distance increases, however, the objectionable reactions of some individuals will be less, but the undesirable situation will still be there.

Consideration should be given to the various sizes of screens upon which stereoscopic motion pictures will be projected. The producer considers this variance in screen sizes in preparing the films for distribution.

Figure 3 shows the convergence required of three individuals sitting in a theater viewing a stereoscopic picture with a close-up (crossed) disparity of 6 in. — "A" sitting 75 ft from the screen, "B" 50 ft from the screen, and "C" 25 ft from the screen. The 6-in. foreground disparity will cause A, B and C each to see the object of regard at the point where



Unequal focus often is a cause of binocular disturbances.

Figure 4

the visual axes of each cross. C must converge over three times as much as A to fuse the two pictures.

Figure 4 illustrates the effect of background disparities on the accomodative-convergence relationship. Accommodation must be maintained on the surface of the screen while convergence relaxes. If the background disparities are greater than the interpupillary distances of the theater customers then an unnatural demand for divergence is made upon them. Such a demand is undesirable for the average individual.

Out of focus or "soft focus" photography should be avoided in all stereoscopic work. All details on the screen must be sharp and clear to avoid disturbances to the accommodative-convergence associations of the audience.

Let us take another example of a customer sitting in the middle of the theater 50 ft from the screen. This man has never had a professional eye examination. He has gone blithely along under the assumption that his vision was efficient because he was comfortable. The facts of the case are that his two eyes do not focus at the same plane. While one of them is looking at the screen, the other theoretically will be out of focus. In ordinarily occupations this person has learned to suppress mentally the vision of, say, his right eye. Had he not learned to do this at an early age he surely would have been uncomfortable because the images of the two eyes were not compatible. Confusion as well as discomfort would have resulted.

He puts on his polarizing spectacles. The powerful stimulus of a large stereoscopic picture with motion, sound and color, suddenly hits him. His habitually suppressing eye cannot ignore it. Confusion in his seeing, with resulting discomfort, begins to plague him. Surely he should not blame the producer, the exhibitor or the stereoscopic system. He is in need of visual attention, and the stereoscopic motion pictures should receive credit for identifying this need. Previously he was comfortable but inefficient in some of his visual skills.

The chances are nine to one in his favor that a visit to an ophthalmic practitioner will bring many benefits to him. After proper lenses have been fitted, one of these benefits should be the ability to view three-dimensional films with comfort and full appreciation of true stereoscopic seeing. The doctor may wish to prescribe frequent attendance at stereo features so that the two eyes will be further stimulated to work together as a team.

Stereoscopic motion pictures will bring to the public many benefits which go far beyond the entertainment factor. For example, facts gathered over the past 14 years of extensive research at Purdue

University under the direction of Joseph Tiffin, have demonstrated that our binocular seeing performance is related directly to out occupational performance.[11] Some of these relationships are:

1. Freedom from accidents.[4,5]
2. Productiveness.[6,7,8,17]
3. Freedom from discomfort on visual tasks.[7,8,17]
4. Accuracy in assembly, inspection and other fine work.[9,10,17]
5. Like, or dislike, of certain activities.[8,16,17]

Seeing is something we do. It doesn't just happen to us. It is a complex act and not a unitary function such as the ability to see clearly with each eye at a distance. Some of us see skillfully and well. Others do it clumsily and inefficiently. Some of us do it effortlessly while others do it with apparent difficulty and discomfort.[18]

Furthermore, seeing is different from other measurable human characteristics such as finger dexterity, temperament, motivation, intelligence or height and weight. Something can be done to improve it when it is below desirable standards. The ophthalmic practitioner can, in a high percentage of cases, transform inefficient, clumsy or uncomfortable visual performance into smoothly performing, effortless and skillful seeing. With the advent of stereoscopic motion pictures he will find facilities which will help him with many of these cases.

Fortunately for the segments of the motion-picture industry concerned with stereoscopic productions, the trend toward the diagnosis and treatment of binocular imbalances has proceeded at a very rapid rate during the past two decades. The benefits are not one-sided. Those pioneers in the ophthalmic field who long have recognized the importance of efficient binocular vision will now have a powerful ally to help focus attention on stereoscopic seeing. The public will be the beneficiary from this added attention to its visual needs.

This is the age of vision. It is the age of speed and precision. The work load has been lifted from men's backs and placed on their eyes. In our factories, offices and schools, and on our highways, the need is for visual skill and for judgment based on visual perceptions. We read gauges, make adjustments of delicate instruments, inspect through microscopes, move levers which guide rapidly moving machines. The task of reading reports and preparing blue prints is never done. The common laborer who can rely on casual vision is becoming rare. The farmer can no longer plod wearily behind the plow. He drives machines, keeps books. This is the age of TV and 3D.

The ophthalmic professions and the ophthalmic industry have met the challenge. As an example, Bausch & Lomb Optical Co. initiated research in the field of vision as it relates to our occupations, and established a research grant at Purdue University. The ophthalmic professions gave active support.[15] Managements of many of our leading industrial and commercial companies cooperated by testing the visual performance of thousands of employees on a large variety of jobs. They assembled measures of employee success, such as accident experience, records on absenteeism, hospital visits, tenure on the job, earnings, quality and quantity of work.[13,14] The statistical analysis of these data provided factual evidence to establish:

1. That stereoscopic testing instruments are necessary to provide an accurate profile of an individual's binocular performance.[12]

2. That stereoscopic factors of vision are important in our everyday occupations.[13,14]

3. That giving consideration to each eye independently, without also giving equal attention to how the two eyes perform as a team, can be unfair to the individual.[11]

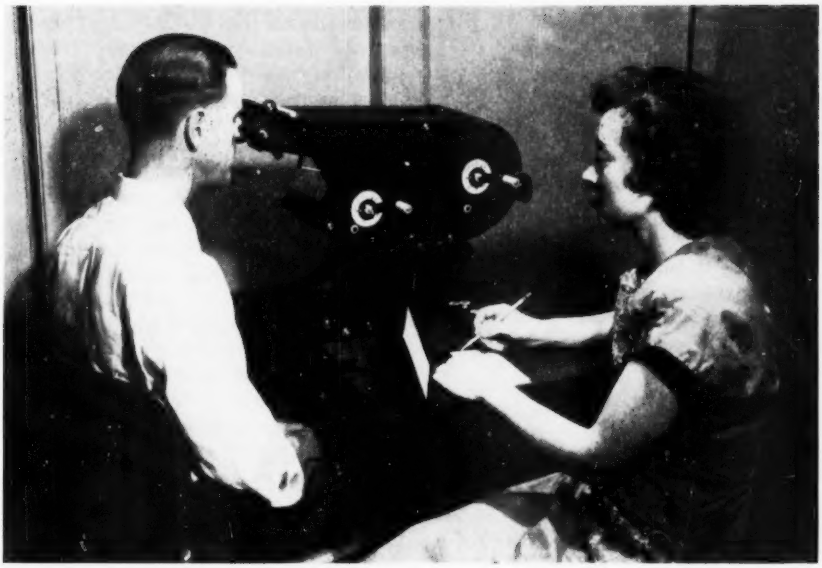


Fig. 5. The Ortho-Rater: a stereoscopic instrument for testing visual skills.

The visual testing instrument that resulted from these extensive investigations was the Ortho-Rater (Fig. 5). It provides highly reliable tests of 12 of the most important visual skills.[12]

Instruments of this type are used widely in industrial and commercial companies, in the military forces, and other areas. When one thinks of the motion-picture industry, the question might well be asked, "Do all of the individuals concerned with the production and projection of stereoscopic films possess the visual qualifications which will permit them to handle the job most efficiently?" Tests such as are contained in the Ortho-Rater might provide revealing information.

It is conceivable that the use of an instrument of this type will enable one to predict the probabilities of an individual's sitting through a 90-min stereoscopic feature without apparent visual discomfort. On the assumption that such a visual standard could be established, we could then say that those who meet the standard could probably view the stereoscopic pictures without discomfort or effort, and that those who fail the standard should seek professional eye care for the sake of their own health and general well-being, even though they are not planning to view stereoscopic motion pictures. We also could tell them that, according to the laws of probability the chances are nine to one that they would be benefited by professional eye care. In addition, a small but very important percentage of those who fail to meet the standard, and who consult a professional man, will discover that the cause of their low visual performance is a pathological difficulty not originating in the eyes even though it reflects in impaired visual functioning.

During the period between 1850 and 1870, Dr. Oliver Wendell Holmes did much to popularize the stereoscope which

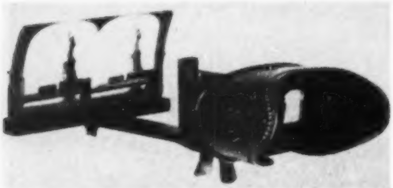


Fig. 6. The Holmes model of the Brewster Stereoscope.

bears his name (Fig. 6). This instrument occupied a prominent place on the parlor table of every cultured home at the turn of the century. In the *Atlantic Monthly* of 1859 Dr. Holmes wrote, "The Stereograph is to be the card of introduction to make all mankind acquainted." In response to this statement of nearly 100 years ago, some have smiled and said that Dr. Holmes did not foresee the impact of rotogravure, motion pictures, radio and television. Others today can smile and say that his prophecy is being fulfilled now that the stereoscope has come to motion pictures, and in the future may come to television.

Dr. Holmes saw the educational value of the stereoscope but he did not foresee it as a therapeutic instrument. Javal first used the stereoscope for the treatment of crossed eyes (squint) as as early as 1895.[22] Since that time it has been the accepted means for visual training (orthoptics). In fact, some form of the stereoscope is the only means known for developing good binocular habits in those individuals who have the basic ingredients for normal two-eyed seeing but who have not learned to use them efficiently.

Motion pictures greatly extend the use of the stereoscope in this important field. They remove one of the restraining barriers that have limited visual

Fig. 7. An Ortho-Fuser in use. The kit contains 5 vectograms of stereoscopic design, bound with instruction sheets in booklet form, and a pair of polarized spectacles.

training. Previously the monotony of the treatment and lack of interest on the part of the patient in viewing diagrams and charts in a stereoscope challenged the ingenuity, resourcefulness and patience of the practitioners and technicians. Now for the first time thrilling drama, with color and stereoscopic effect combined, can be used as a valuable supplement to the specific, controlled, clinical procedures in the professional office.

In view of the widespread use of stereoscopic testing and training instruments today, and in view of the imminent wide-spread use of stereoscopic motion pictures, we believe we can paraphrase Dr. Holmes' prophecy and state, "The stereoscope will be the card of introduction to make those who need visual attention acquainted with the ophthalmic professions."

When one considers the superb entertainment, educational, cultural and therapeutic values of properly produced, properly projected and properly viewed stereoscopic motion pictures, he can justifiably ask, "why should not every school child have the opportunity of viewing them periodically?" The powerful stimulus to better binocular vision will in this way be brought to the child during the formative years, while he is developing the pattern of seeing habits that may stay with him through life. Our first consideration, however, is to be sure that his *eyes are right.* The nation-wide showing of stereoscopic motion pictures will help to create the desirable awareness of the need for more attention to our children's vision. In consequence it will hasten the day when we can be sure that their vision is adequate for their various activities.

The educational job must not be a publicity program. It must be an orderly and constructive procedure that will earn the cooperation of the many strong allies who also are keenly interested in the success of the motion-picture field's program.

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Discussion

Lt. Col. Robert V. Bernier (*U.S. Air Force, Wright Air Development Center, Dayton, Ohio*): Since, when we are looking at physical objects at say 10 ft, objects further in the distance appear relatively in focus, is it not true that we could have convergence up to a point 10 ft from our position in the theater and still be relatively focused for image matter on the screen without discomfort?

Mr. Sherman: Yes, if you mean that the camera can be as close as 10 ft; was that your point?

Lt. Col. Bernier: No, Sir, I mean if the displacement of images for the crossover, as you mentioned, was such that the convergence occurred at 10 ft from your viewpoint, as you're sitting in the theater, would not the subject matter or the image on the screen be in relatively good focus even though we were converged and accommodated for that 10-ft position? When we look at physical things in real life, 10 ft away, objects in the medium and far distance up to infinity appear relatively in good focus.

Mr. Sherman: Yes, I get your point. When you look at an object — suppose I look at Dr. Frayne, 10 ft away. I have to accommodate to see him sharply. I need to converge. I need to do both. Now, if I converged on Dr. Frayne and focused on the wall over there, which I am doing now, he's very blurred. Or if I converge on the wall and focus on Mr. Frayne, I see two of him. Is that bad?

Lt. Col. Bernier: No, I didn't mean that. I mean to imply that this thing of optical infinity, you consider what? 20 ft?

Mr. Sherman: Let's say 20 ft. 26 ft rather.

Lt. Col. Bernier: That means that for objects in physical life beyond 20 ft, everything as far as the individual is concerned is in focus regardless of where you are converged. Isn't that true? Then that would imply that in three-dimensional motion pictures you could have objects appearing as close as 20 ft from your position in the theater and still be in focus for the image which is on the screen.

Mr. Sherman: Yes. I think I get your point. The only difference is that I change both my accommodation and my convergence when I change fixation from a distance to him. However, if I were looking at a projected stereo picture taken of him with the camera placed where I am standing, my accommodation would need to be on the surface of the screen while my convergence is directed toward the picture in front of the screen. This would not be an undesirable situation and should cause no discomfort.

Charles Smith (*Stereo Techniques, Ltd.*): Dr. Sherman listed among his requirements for properly projected and properly produced pictures that on background objects the displacement of the two image points should not be greater than 2½ in., which causes the eyes to squint outwards. Now, as we know, on some of the pictures that we've seen this limit of 2½ in. is very greatly exceeded on background objects, with unpleasant results. I'd like Dr. Sherman to tell us whether he considers that in this case the results are actually harmful to the eyes, or merely unpleasant.

Mr. Sherman: They are only unpleasant. The eyes are not hurt by diverging. The physical eye cannot be hurt by viewing stereoscopic motion pictures providing there is no pathology that requires abstinence from normal seeing tasks. Discomfort is all that might be induced.

Edward Stanko (*RCA Service Company, Camden, N.J.*): Isn't it possible to overdo the stereoscopic effect? Recently I noticed that in some of the 3-D pictures they'll have a tree or some other object very close to the camera, then there will be a set 15 or 20 ft away, and then further back there will be a background scene. Now that's a considerable distance for the eye to cover. Do you think that sustained photography under such conditions might produce eyestrain?

Mr. Sherman: Yes, it might cause a little discomfort and particularly with those individuals who do not have adequate flexibility between the functions of accommodation and convergence.

Mr. Stanko: In regard to your suggestion that stereoscopic pictures are beneficial to the eye, I've had some personal experience with my own son. When he was a small boy he had one crossed eye. By using these stereoscopic pictures and eye exercises he was able to improve his vision considerably.

Mr. Sherman: Well, that's interesting. We should keep in mind that flexibility in visual functions can be developed through some of the stereo pictures which at first might cause some discomfort.

Nic Archer (*Univ. of California Student*): Do you consider the Viewmaster Stereo Viewer to be of an optical quality to be beneficial to small children?

Mr. Sherman: Those I have seen have been excellent.

Lawrence Brunswick (*Colorvision Inc.*): Following up Mr. Stanko's mention of the sets with the very great depth, I think that brings out the aspect that so much of our stereo work is done with too great an inter-pupillary distance between the two lenses, and that causes that great disparity. That has to be carefully watched, I believe.

Mr. Sherman: That's one of the points of properly produced stereo pictures that we have stressed in this paper. Yes, desirable interaxial distances in the stereo camera are an essential ingredient.

Dr. Feinberg (*Northern Illinois College of Optometry*): I wish you would amplify a comment you made about vertical imbalance or the effects induced by improper displacement vertically by the projectionist.

Mr. Sherman: There are 2% of us in this room, if we're average individuals, and I assume we are, whose right eyes tend to tilt upward; another 2% whose left eyes tend to tilt upward. If for example, the left-eye frame is higher on the screen than the right-eye frame, the 2% of us in this room whose left eye tends to tilt upward would have their condition eased while the 2% whose right eye tends to tilt upwards plus the 96% whose two eyes are in normal vertical balance would be penalized. I have a friend with a Stereo Realist camera and a 3D Stereo Projector. He has a right vertical imbalance and when we visit him he tries to project his pictures with the right-eye frame slightly higher because *he* sees them comfortably that way. For the sake of the 96% of the people who have normal vertical balance, let's keep the frames in synchronization in vertical alignment. Then the identifying finger is going to be on the 4% that ought to see some of these eminent professional men who are here this afternoon. Otherwise the other 96% are likely to go.

Mr. Stanko: Mr. Sherman, could you give a brief explanation of why a stereoscopic picture appears to be smaller the minute that you add depth to it? I've noticed that the large screens that were used in theaters, which apparently seem to be large for 2-D pictures, but the minute that you put a 3D picture on it, it shrinks right down and comes right to you and gets smaller. Can you give a brief and simple explanation of that?

Mr. Sherman: Very briefly, this phenomenon is in the field of our psychological factors of vision. We converge on an object when it is near to us. Interpretatively we think of it as being nearby and at the point where our visual axes cross. It's in the mind, strictly, and it's related to our convergence interpretations. The factors of convergence and accommodation control the suggestion of relative sizes.

John G. Frayne (*Westrex Corp. and Chairman of the Session*): I think that that question will be answered in more detail tomorrow afternoon in the paper by Dr. Hill of the Research Council.

Mr. Sherman: Dr. Frayne, may I make one other comment. Were we to get into the clinical aspect of visual performance and of how we see, I'm not the one who should answer that. Rather it should be the men in clinical practice who are in the audience. When it comes to the relationship between how we see, and how we per-

form at occupations we will try to answer questions.

Winton C. Hoch (Cinerama Productions): How much convergence disparity can your 80% of well-adjusted people accommodate?

Mr. Sherman: In a well-conducted clinical study of around 4,800 cases, Dr. Tait plotted the latitude between accommodation and convergence. It ranged all the way from zero — people who seem to have no latitude, at one extreme, to the other extreme where there was a very high latitude. In other words, with some individuals the stimulation to one function does not affect the other. But the average latitude is about 8 prism diopters. Now the recommendation that we made this afternoon that the crossed disparity — or near-point disparity — should not exceed 1/20 of the distance from the nearest spectator to the screen, requires only about 4½ prism diopters of latitude as we refer to it. So the limits I have indicated still leave an ample latitude between what 80% of the people have and the limits I indicated.

Mr. Hoch: Could you restate that in terms of an illustration? If a person were sitting in the middle of the audience, say 50 ft from the screen, how close could the image appear stereoscopically to him, and satisfy your requirement?

Mr. Sherman: Within 4 ft.

Mr. Hoch: That would apply to, say, 80% of the viewing audience?

Mr. Sherman: About 80% will have the visual mechanism and the performance to do that, providing it is not sustained, providing it's momentary.

Mr. Hoch: Then there is a time element also included?

Mr. Sherman: Oh, yes. If it were to be there for a minute or two at that one spot, why some people would feel it, even among the 80%. But if it's momentary there should be no problem.

Visual Monitor for Magnetic Tape

By ROWLAND L. MILLER

This monitor presents visually the information recorded on magnetic tape without employing auxiliary equipment such as movable scanning heads, amplifiers, etc. The presentation is a variable-area display that indicates frequency and amplitude. The display remains stationary as long as the tape is motionless in the Magnescope, but movement of the tape is accompanied by corresponding movement of the display. Magnescope consists of a unique cathode-ray tube and its associated power supply. The cathode-ray tube is so constructed that the magnetic fields from the tape directly influence a beam of electrons which produces the variable-area display.

The Magnescope is a visual monitor for magnetic tape. It gives visual presentation of the information recorded on the tape without employing auxiliary equipment such as movable scanning heads, amplifiers, etc. The presentation is a variable-area display and thus gives indication of frequency and amplitude. The display remains stationary as long as the tape is motionless in the Magnescope, but movement of the tape is accompanied by corresponding movement of the display.

Magnescope consists of two units connected by a single cable (Fig. 1). One of these units houses a unique cathode-ray tube which produces the visual display. This unit is equipped with proper guides to accommodate various magnetic tapes. A hold-down mechanism is provided, which, in conjunction with the guides, assures correct positioning of the tape. Since this unit would normally be in front of the user it includes an On-Off switch, pilot lamp and fuse. The second unit is the power supply and includes all adjustable controls. Once the controls are adjusted for a particular cathode-ray tube there is apparently no reason for readjustment for the life of that tube. This unit normally rests on the floor or any other convenient place.

The cathode-ray tube which produces the display is similar in shape to electrostatic deflection tubes of comparable size. At one end of the tube is a gun structure. At the other end is a medium persistence screen. In between these extremities is a metallic section about 4 in. long which makes the operation of the tube possible.

The gun structure consists of a heater, cathode, grid and first accelerating anode and, as in conventional cathode-ray tubes, the structure supplies the electrons and shapes them into a suitable beam. The potentials on these various elements

Presented on April 30, 1953, at the Society's Convention at Los Angeles by Rowland L. Miller, Magnescope Corp., 1147 N. McCadden Pl., Hollywood 38, Calif. (This paper was first received on March 25, 1953, and in complete form on July 29, 1953.)

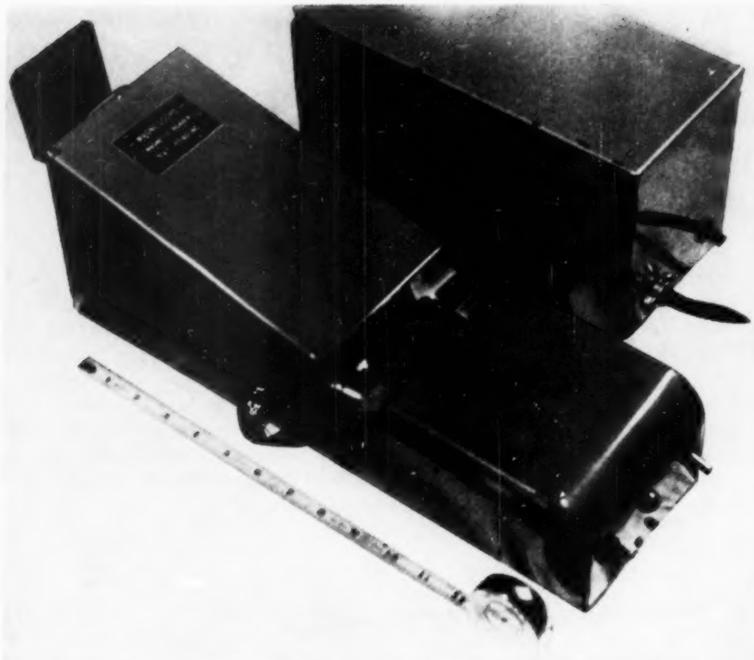

Fig. 1. Experimental demonstration model of the Magnescope.

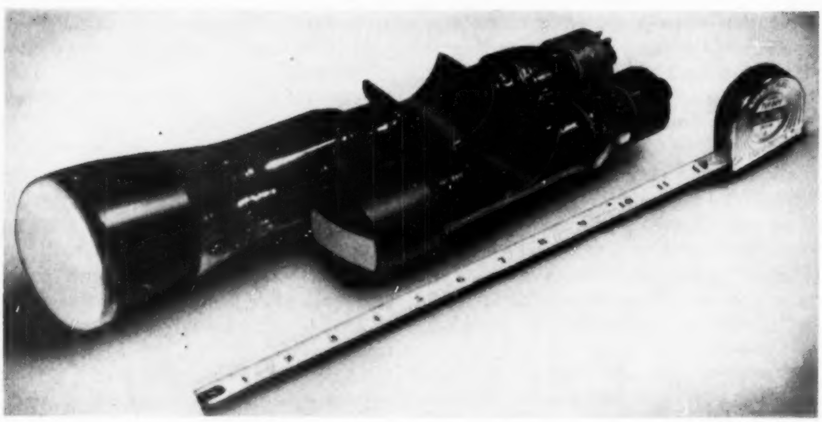

Fig. 2. 2-in. and 3-in. tubes. The second anode and saddle can be seen near the center of each tube.

are adjusted so that the electron beam leaving the gun structure is cone-shaped, with the apex of the cone at the first anode.

The forementioned metallic section near the center of the tube is the second anode, which is specially designed and serves several functions. It positions the tape (in conjunction with the guides and hold-down mechanism), forms the electrons into a properly shaped beam, and accelerates the electrons toward the screen after they have been deflected by the magnetic fields of the tape. Near the center of the anode and at right angles to its axis there is a cylindrical trough known as the saddle. Figure 2 shows the second anode and the saddle. In the bottom of this saddle is a thin window of nonmagnetic material. When the Magnescope is in use the magnetic tape passes through the saddle with the recorded area directly against the window. The magnetic tape, therefore, passes through the saddle and at right angles to the axis of the tube.

The cone-shaped beam of electrons entering the second anode is formed into a ribbon-shaped beam by suitable elements in the anode and the electrons in this ribbon pass directly underneath the window in the saddle. The potential on this anode is such that the electrons are accelerated toward the screen. The electrons, upon striking the screen, produce an illuminated band across the center of the screen which is parallel to the window. In the absence of magnetic tape in the saddle the electrons travel in trajectories which are determined by the beam-forming elements only and pass through the tube to form the illuminated band as outlined above. However, when the recorded area of the tape is placed at the window in the saddle the magnetic fields surrounding the tape extend through the window and into the ribbon of electrons directly below. The introduction of these fields changes the trajectories of the electrons and the upper edge of the illuminated band is now distorted. The amount of distortion is a function of the size and strength of the individual fields.

It is not the purpose of this paper to analyze the magnetic fields produced by the recording on the tape, but the track acts almost as if it consisted of very small magnets placed laterally across the track area and adjacent along its length. Continuing this analogy further and considering a single frequency only, each magnet would be magnetized and have a dimension of one-half wavelength in the longitudinal direction of the track. Furthermore, the magnets would be placed with like poles adjacent. Each magnet (half-wavelength) would have a closed external magnetic field between its poles, but, due to the placement of the magnets with like poles adjacent, the directions of these fields will be reversed for consecutive magnets. Thus there is a reversal of field for each half-wavelength.

As the electrons enter these fields they are deflected toward the tape or away from it, depending upon the direction of the magnetic field. Since the electron deflection is always normal to the direction of the field, the deflection upward and downward will not be symmetrical about an axis. The reason for this is that for a recorded sine wave each half-wavelength field acts as if it were approximately semicircular in shape. For a field direction which deflects the electrons away from the tape, the electron deflection assumes this semicircular shape and the bottom half of the cycle is approximately semicircular. For the other half of the cycle where the field direction is such that the electrons are deflected toward the tape a different situation exists. Because the deflection is normal to the semicircular field the electrons are deflected toward the center of the field as well as upward and this half of the cycle assumes a spike shape.

The net result of this is that for recorded sine waves the display is a series of cusps — one for each cycle. This effect diminishes with decreasing frequency

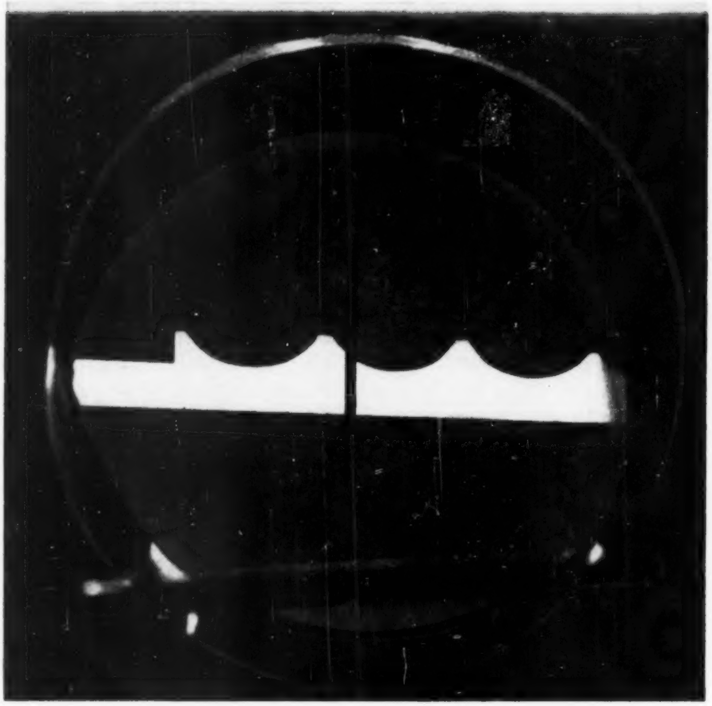

Fig. 3. 100 cycles/sec as seen on the Magnescope. The recording circuit was turned on at the peak of the cycle (left side).

and at frequencies of 100 cycles/sec or less the display assumes a sine-wave shape (see Fig. 3). At frequencies of several thousand cycles/sec the display appears almost as a series of spikes. This effect is not detrimental to the purpose for which the tube is intended, however.

The area scanned at any one time is slightly more than one frame. The limit of resolving power is about 6000 cycles/sec for a 3-in. tube. The amplitude of the display is about $\frac{3}{8}$-in. for a 100% modulated track. A signal 30 db below 100% modulation can be seen.

Experimental tubes with 2-, 3-, and 5-in. screens have been made. In each case the geometry of the gun structure and second anode is identical. The 2-in. tube is about $8\frac{1}{2}$ in. long and is intended to be adapted to existing film editing machines to give visual monitoring for film editors. The 3-in. tube has applications outside of the motion-picture industry. The 5-in. tube was developed for research in cardiology. In each case one frame covers the face of the tube. The tubes will handle all existing track including the "three strip."

Only experimental tubes have been made up to the present time and the 3-in. tube has been incorporated into the Magnescope for display and demonstration purposes. The final form of the Magnescope has not been determined. The needs of the industry must be served and these needs will determine its final outcome.

Discussion

George Lewin (Signal Corps Pictorial Center): Have you given any thought to making the track that you're looking at audible at the same time, so that it would be an additional help to editing?

Mr. Miller: Yes, we have. However, this tube is a static device as well as a dynamic one. In other words, the display is visible when the track is motionless and you see a variable-area picture on the tube of what's recorded on the track. Now the disadvantage of coupling this directly to some audible reproducer is the fact that for audible reproduction the track must be moving, which, in a sense, defeats the purpose of the tube.

Mr. Lewin: Can't you pick up the beam just as you pick up the scanning beam in an iconoscope and just the part that's stationary would then be repeated over and over again if you scanned it slowly enough? If you could scan at the speed corresponding to its normal tape motion, then it ought to give you an intelligible reproduction of the particular syllable or words that are in the aperture at that moment.

Mr. Miller: Yes. You mean incorporate a photoelectric cell into the beam somehow. Is that what you meant?

Mr. Lewin: Either that, or the beam itself could be fed into a tube, and amplified as it's scanning so as to give you an audible signal, provided the scanning is kept down to about the speed of the normal tape motion.

Mr. Miller: Yes, that could be done, except that there again the tape must move at some speed, the speed at which it was recorded and when that happens, you will not see the pattern of the tape. The tube was made to find footsteps, all kinds of sound effects, beginnings and endings of music and words and blank spaces. If the tape moves slowly through the tube you can see all of those things. If you move the tape at the speed at which it was recorded in order to reproduce it, then the tube is ineffective. Do you see my point?

Mr. Lewin: Yes, I see your point. It's entirely possible that what I have in mind is impossible to accomplish. What I picture in my mind is that you have this electron beam scanning across, say, a short piece of the tape.

Mr. Miller: It's continuous. The electron beam is a solid ribbon of electrons that goes directly beneath the tape and is about a frame wide. There is no scanning.

Mr. Lewin: I see. I thought it was the electron beam scanning across it.

Mr. Miller: No. We tried using a beam and scanning but the resolving power was not good, so we gave that idea up.

Mauro Zambuto (IFE Studios, N.Y.C.): I would like to know what happens when this gadget is used in connection with multiple tracks? Because if I understand it correctly, the direction of motion of the electrons in the beam is across the width of the tape. Therefore if we have a tape that has three tracks, one beside the other, the beam would be modulated in sequence by the signals of each of these tracks so that we would have practically a mixed signal of the three tracks.

Mr. Miller: This is a curved section (the saddle) and the film follows that curve. Now, the track that you are interested in is placed directly over this window. The other two are far enough removed so that they do not deflect the electron beam. Then to see either of the other two tracks you merely need to re-position the tape to select the track you desire to see.

Mr. Zambuto: That means that the active part of the tube is limited to about 100 mils or less.

Mr. Miller: That's right.

Mr. Zambuto: What is the order of magnitude of the accelerating voltage in the tube?

Mr. Miller: You mean the speed of the electrons?

Mr. Zambuto: That's right. I mean first of all the speed of the electrons near the window, and then the speed of the electrons when they hit the screen. Is there any difference between the two?

Mr. Miller: They move slowly in this region (near the first accelerating anode) and then are accelerated after deflection.

Mr. Zambuto: So the main acceleration would happen after this deflection?

Mr. Miller: That's right.

Mr. Zambuto: May I ask the order of magnitude again?

Mr. Miller: They hit the screen with a velocity of about 20,000 to 25,000 miles

per second and in this region near the saddle they're traveling about 4000 miles a second. If you're interested, a 100% track, according to calculations, has an external magnetic field of about 1.6 gauss.

Mr. Zambuto: Exactly 1.6 gauss?

Mr. Miller: That's what it's calculated to be.

Mr. Zambuto: By external field you mean field at the surface of the window?

Mr. Miller: That's right.

Mr. Zambuto: And, of course, there is something to keep the film in close contact with the window?

Mr. Miller: That's right. There is a hold-down mechanism plus some guides that rotate and have proper width slots to select films of various widths.

Mr. Lewin: Is there any clear indication that can be seen in the display when 100% modulation or any specific level on the tape is attained? What I'm thinking of is whether it can be used to tell how near your are to the overload point of the tape.

Mr. Miller: 100% modulation of the tape has been arbitrarily defined as the point where 12% intermodulation is present when the track is reproduced. That has been called 100% modulation and represents a certain amount of audio power into the recording head. However, this power can be exceeded considerably without getting too much additional distortion. Due to the latitude of the tape, it is impossible to determine 100% modulation precisely by observation. However, if you just keep putting on more and more level you will come to a point where the film evidently becomes saturated, but that is way above what is called 100%.

Mr. Lewin: Do you foresee any possibility of modifying the tube so the display would look like a sine wave?

Mr. Miller: That's very difficult to do. In fact, Dr. A. M. Zarem has asked the same question but it's an extremely difficult problem. In fact, it may be impossible.

Francis Oliver (*Imperial Productions*): Could you tell me what order of magnitude of wavelength the tube would be able to stand?

Mr. Miller: At a speed of 90 fpm, which is standard motion-picture speed, the resolving power is about 6000 cycles. Now if the film is recorded at a slower speed, say at 45 fpm, the resolving power would drop down to approximately 3000 cycles. This is not a deficiency in the tube. It's a deficiency of the eye. You just can't see the spikes because they're beyond the human resolving power.

Mr. Oliver: Would there be a possibility of spreading this out or magnifying it electronically so it could be seen?

Mr. Miller: Yes. In fact, we made a 5-in. tube which is being used for research in cardiology. Just make the screen larger and the tube correspondingly longer and the resolving power goes back up.

Mr. Oliver: I don't know if your company has thought about it or not, but the computer field probably would have some interest in this for read-out equipment to display magnetic pulses. That is why I was interested in the magnitude of wavelength — would you estimate 2 mils, 3 mils, 8 mils in length?

Mr. Miller: Let's see — 6000 cycles is what in terms of 90 fpm?

Mr. Oliver: A mil and a half, something like that.

Mr. Miller: If you use that as a basis . . ..

Mr. Oliver: You say 9000?

Mr. Miller: 6000. Now 7000 and 8000 are on the tube, but you can't see them with the naked eye.

Mr. Oliver: Well then, you'd say that it will resolve, say, 7000 or 8000, and then we could magnify it so that we could actually display it?

Mr. Miller: That's right. You could do that.

C. E. Cunningham (*U.S. Navy Electronics Lab., San Diego, Calif.*): So far the device described is a qualitative device. Do you hope you can make quantitative measurements with it? That is, will you have a calibration scale on the front of the tube?

Mr. Miller: Yes, a calibration scale can be put on it, both in terms of frequency and in terms of amplitude.

Mr. Cunningham: Secondly, what about dynamic range? Will it cover the full dynamic range of the tapes now in use?

Mr. Miller: Well, the tube will go up to 8000 cycles. It is fundamentally an electron microscope, and the thing that limits its resolving power is the screen material. At about 8000 cycles the deflections are comparable to the size of the

material of which the screen is composed and the resolving power then disappears.

Mr. Zambuto: I wanted to know whether varying the wavelength affects the vertical displacement of the beam on the screen, my point being that very high frequencies on a tape produce a field that is much closer to the tape surface than the field produced by a low-frequency signal. Does that influence the displacement of the electrons?

Mr. Miller: Yes it does. For 100% recorded levels at all frequencies the amplitude is greater at low frequencies than at high frequencies.

Mr. Zambuto: Then it seems to me that that would be the element limiting the frequency response of the apparatus. Because, granted that you can spread the beam horizontally by an electronic device, you would still be limited by the maximum vertical displacement that you can get out of a certain wavelength.

Mr. Miller: That is true, but you will still get a usable vertical displacement up to 8000 cycles and then the distance between the wavelengths becomes comparable to the particle size that makes up the screen. Now, by making a longer tube and getting effective magnification in both directions, vertical and horizontal, then you can go on up in frequency.

Mr. Oliver: Could you tell me the diameter of the scanning beam — the electron beam?

Mr. Miller: There's a continuous ribbon of electrons about a frame wide in the horizontal direction and about $\frac{1}{8}$in. thick in the vertical direction, and the tape rides across the top of that ribbon and deflects the upper edge.

Westrex Film Editer

By G. R. CRANE, FRED HAUSER and H. A. MANLEY

This paper describes a film-editing machine which employs continuous projection resulting in quiet operation. It accommodates standard-picture and photographic or magnetic sound film as well as composite sound-picture film. Differential synchronizing of sound and picture while running, automatic fast stop and simplified threading features in the film gates with finger-tip release materially increase operating efficiency.

The Westrex Editer has been developed to provide facilities for editing 35mm motion-picture film, in a single integrated unit, for meeting the various and often conflicting requirements of the motion-picture field. The unit described in this paper is the result of extensive field surveys supplemented by consultations with many members of the film-editing profession in Hollywood. Noteworthy among the many improvements offered by this machine is the elimination of noisy operation by the use of continuous optical projection and the substitution of timing belt drives for gear-driven mechanisms.

It was generally accepted that the picture should be projected from the rear on a conveniently located screen and should be visible through a fairly wide viewing angle and with sufficient screen brightness to permit operation in a normally lighted room. It is felt that this has been accomplished to a very satisfactory degree. In addition, means have been provided for projecting an enlarged picture on a wall, the projection distance and resultant picture size being accommodated by the selection of a simple spectacle lens. Considerable attention has been given to simplicity and efficiency in operation and to the convenience of the operator. Threading of film has been reduced to a minimum of effort. Placing the film in the film trap automatically locks the film to the drive sprocket so that the position of the film cannot be lost inadvertently. Closing the film gate completes the operation. Removal of the film is accomplished with one sweeping motion of the hand. As the hand approaches the film, a flat lever is depressed which completely releases the film. The hand continues in the same direction and removes the film. Touching a different lever opens the film gate without releasing the film from the sprocket to permit the film to be inspec-

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ted or marked without possible loss of its position in the film trap.

A differential synchronizer permits the position of the sound film to be continuously changed with respect to the picture film while the machine is either in motion or at rest. Associated with the differential synchronizer is a dial which counts the number of frames required for synchronism in either direction.

The sound sprocket is driven by a substantially constant-speed motor which is controlled by a foot-pedal switch operated by the left foot. The picture sprocket is driven by a variable-speed torque motor which is controlled by a foot-pedal switch and rheostat operated by the right foot. The film sprockets can be operated independently by their respective motors, or the two sprockets can be mechanically interlocked by the operation of a lever and driven by either motor in the forward or reverse direction. Four illuminated arrows indicate whether each motor circuit is set for forward or reverse operation and a fifth arrow indicates whether the two sprockets are interlocked.

General Description

Figure 1 is a front view of the Editer. The main housing is an aluminum casting which is supported by two formed sheet-metal legs. The height is adjustable over a range of 5 in. to accommodate the operator in seated or standing position. The two foot pedals are also adjustable back and forth to suit the operator. Four castors provide mobility while two jack screws insure operation in a stationary position when desired. The large raised section at the center of the main casting houses the viewing screen and two of four take-up spindles which are optional accessories for operation with 10-in. film reels. An incandescent lamp, located within this housing and operated by a push-on, push-off button

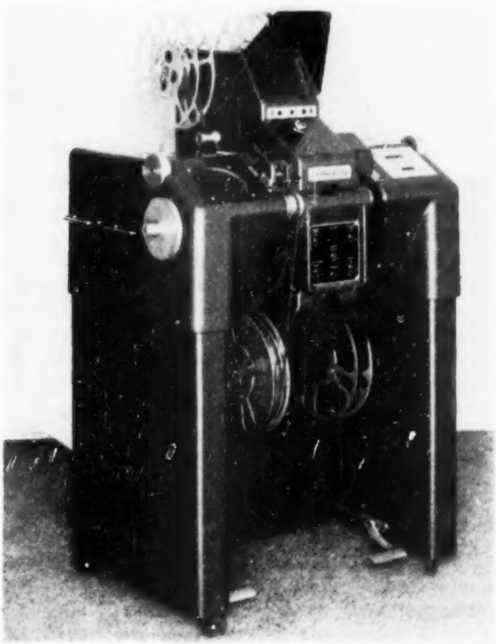

Fig. 1. Front view showing operation with film reels and bag at the rear for collecting film if reels are not used.

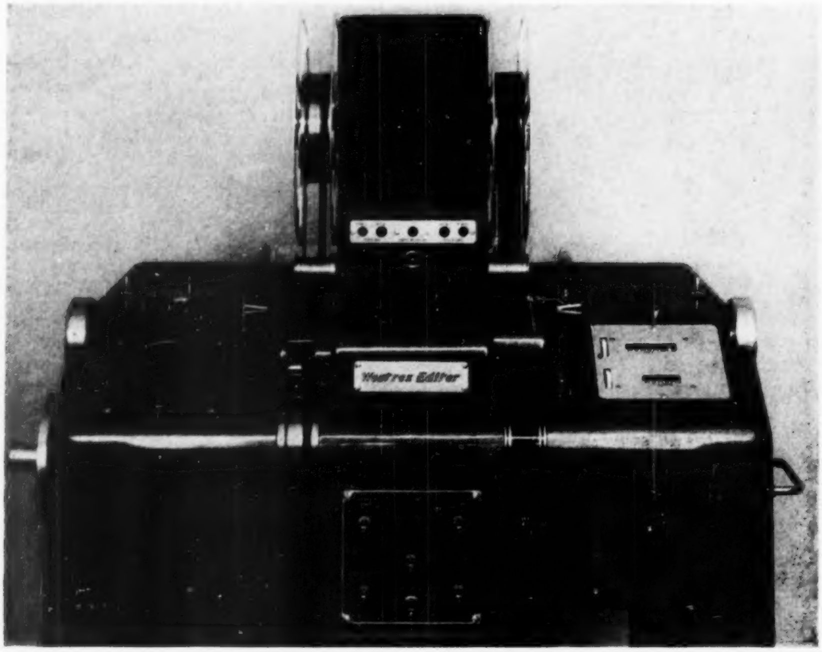

Fig. 2. Close-up of front showing operating controls.

switch, provides a shadow box for viewing film. The hood over the viewing screen is useful where a high level of room lighting exists, but is readily folded back or removed.

The lower take-up assembly between the legs is likewise optional and not present if operation without reels is desired.

A sheet-metal box connects the two legs at the rear near the floor, which provides structural stiffness and convenient housing for most of the electrical components. A removable rear panel gives ready accessibility to fuses, relay and amplifier. All wiring to the upper housing passes through plug connectors.

Controls

Figure 2 is a close-up view of the main housing showing the location of the parts of the equipment and the controls which are used in normal operation of the Editer. The center section starting from the top contains the viewing screen, the five indicator lights, the light-box lamp switch and the circuit control panel. This panel is equipped with sound and projection-lamp switches, a photographic-to-magnetic sound-transfer switch, a switch which operates the constant-speed motor or transfers the control to the foot pedal, a main power switch, a volume control and a jack for phones. To the left of the center section are the reversing switch and handwheel for the constant-speed motor and the differential-synchronizing control. In front of these is the monitor loudspeaker. To the right of the center section are the reversing switch and handwheel for the variable-speed motor, and the framing control. In front of these is the footage counter reading in feet and frames. An optional, additional counter reading sec-

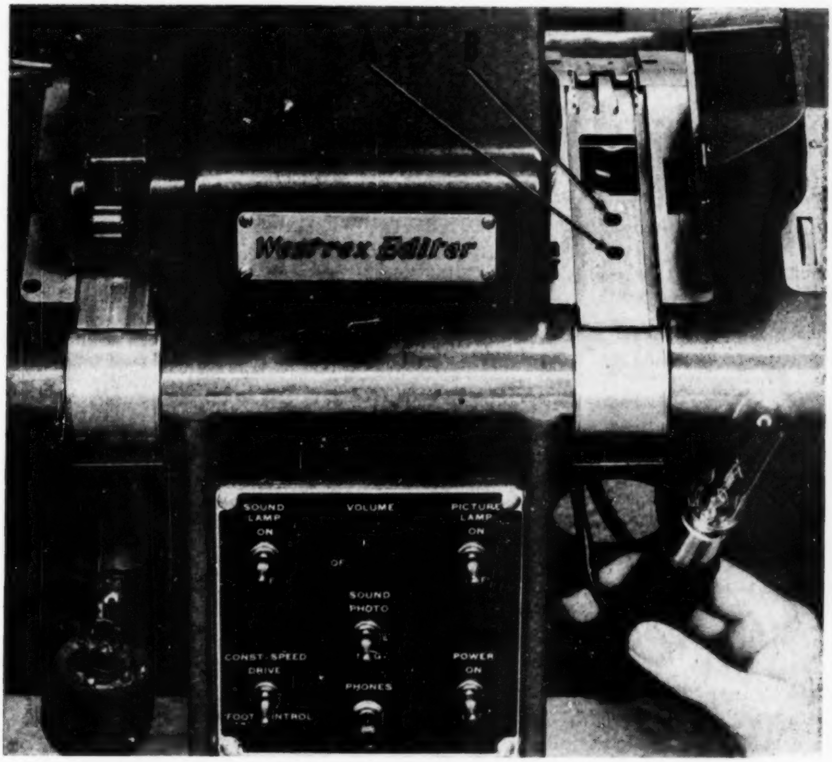

Fig. 3. Close-up showing removable, prefocused lamp mounts.

onds of time is mounted just below the footage counter. The sound and projection lamps are mounted in cartridge-type lamp mountings which are quickly removable from the front of the machine for replacement of lamps, as shown in Fig. 3. Both holders are keyed for registration and held by detents so that no tools or readjustments are required.

Just above the control panel is a lever which rotates through 180° to interlock the sound and picture drive mechanisms. It operates a coupling consisting of an internal gear meshing with an external gear of the same number of teeth, and a one-tooth interval in mesh is equivalent to one sprocket hole. The engagement is spring loaded by the control lever and the indicator light is lighted only when actual mesh is achieved, which may require the rotation of one shaft by a fractional tooth pitch. A high-speed rewind flange is located on the left side of the machine and is normally operated by the constant-speed motor. Several features of the Editer are sufficiently interesting to merit a more detailed description.

The picture system employs continuous projection by means of a rotating 12-sided prism, thus eliminating the noise introduced by the conventional type of intermittent movement. The picture image is projected from the rear on a translucent screen with sufficient light intensity to permit operation in the presence of normal room illumination. The image is $3\frac{3}{4} \times 5$ in. of the same

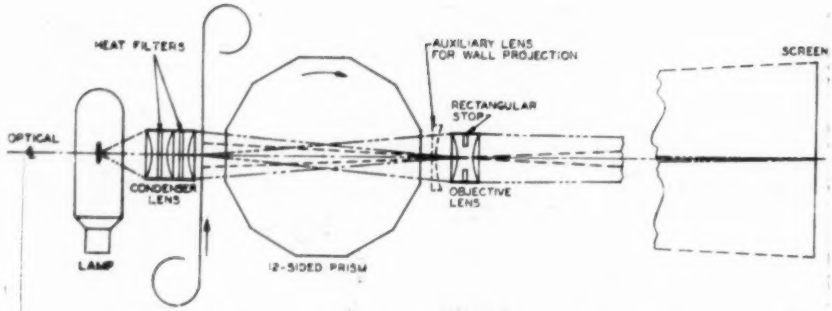

Fig. 4. Optical schematic, simplified by the omission of several mirrors.

orientation as the image on the film; that is, the film in the gate is threaded so as to appear upright and properly oriented from left to right and this relationship is maintained in the projected image on the screen. The quality of the image is comparable to that obtained with intermittent-type systems. The movement of a lever shifts the picture to the right enough to include a view of the sound track of a composite print.

If desired, an enlarged image can be projected on a wall or screen by operating two controls. A knob control inserts a simple spectacle lens in the optical path below the projection lens and a second knob tilts one mirror. This supplementary lens is introduced to focus the projected picture without disturbing adjustments of the normal optical system, and its focal length may be chosen to accommodate any given distance. In this case the orientation of the projected image is also the same as that of the image in the gate. The image size is a function of the distance between the machine and the screen, and for a distance of 10 ft the picture is approximately 15 × 20 in.

Optical System

The continuous-projection optical system is shown schematically in Fig. 4. The filament of the projection lamp is imaged in the objective lens by a three-element condenser lens. Two heat-absorbing filters are located between the elements of the condenser lens, and these filters are sufficiently effective to permit the film to remain stationary in the picture gate for an indefinite period without causing damage to the film. A blower passes sufficient air over the lamp and condenser-lens assembly to remove heat and keep the entire assembly cool. A mirror in the picture gate bends the optical axis at a right angle and directs it through a rotating 12-sided prism. A second mirror deflects the light beam into the objective lens which focuses the film image on the viewing screen. Two additional mirrors (not shown in the schematic) fold the beam for convenience. The prism is driven directly from the picture-sprocket shaft by right-angle helical gears. Framing is accomplished by sliding the drive gear along the shaft to alter the angular relationship between the prism and the sprocket. Several refinements in design reduce gear backlash to a minimum to insure picture steadiness.

The function of the prism in this system for continuous, nonintermittent projection is similar to systems employed in high-speed cameras and projectors, and the fundamental design considerations have been well covered in previous articles[1] and will, therefore, not be repeated here. The authors also acknowledge the significant contribution of L. B.

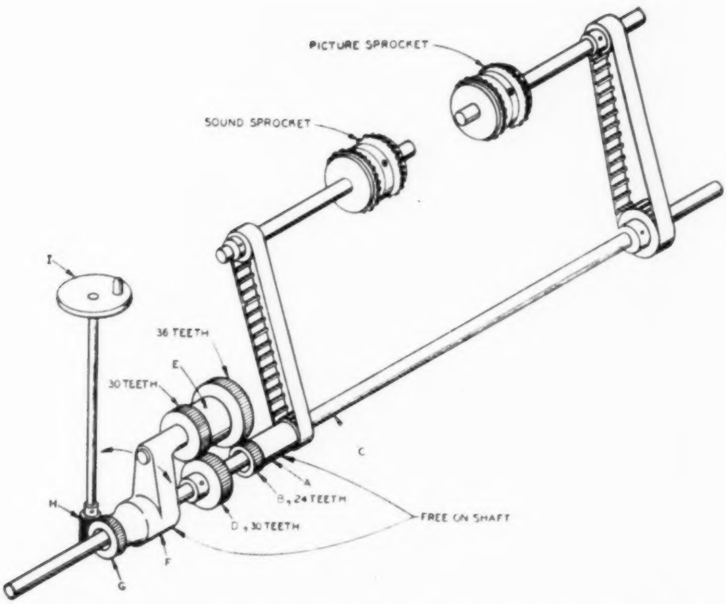

Fig. 5. Simplified mechanical schematic to illustrate use of epicyclic gears to permit changing the position of one film sprocket relative to the other.

Browder in the design of this optical system.

The various considerations of performance and manufacture indicate that the best compromise is a prism having 12 faces. Each face is active for a total rotation of the prism of 30° or plus and minus 15° from normal, plus the angle subtended by the objective-lens aperture. This aperture takes the form of a slit with its long dimension parallel to the axis of the prism to keep its subtended angle at a minimum, consistent with reasonable light conservation. However, due to this aperture effect, successive frames are projected as lap dissolves, the overlap being of short duration, representing the time required for the edge between two prism faces to pass across the effective width of the lens aperture. The prism is shown in Fig. 6 with the adjacent mirror D which turns the axis downward through the objective lens. This mirror is rotatable between stops to shift the image for viewing the sound track. The shift lever is shown as E.

Synchronization Control

Differential synchronization between the sound and picture films is accomplished by a series of gears on the jack shafts in the sound and picture film drives. With the two shafts interlocked, synchronization may be changed by indicated amounts while the machine is in operation or at standstill. Figure 5 is a simplified mechanical schematic of the differential synchronizer. A represents the sound jack shaft on which a gear B is mounted; C represents the picture jack shaft on which a gear D is mounted. The gears B and D are coupled through an integral pair of epicyclic gears E, the shaft of which is mounted on the carrier F. This assembly floats on the jack shaft and may be rotated about it by the

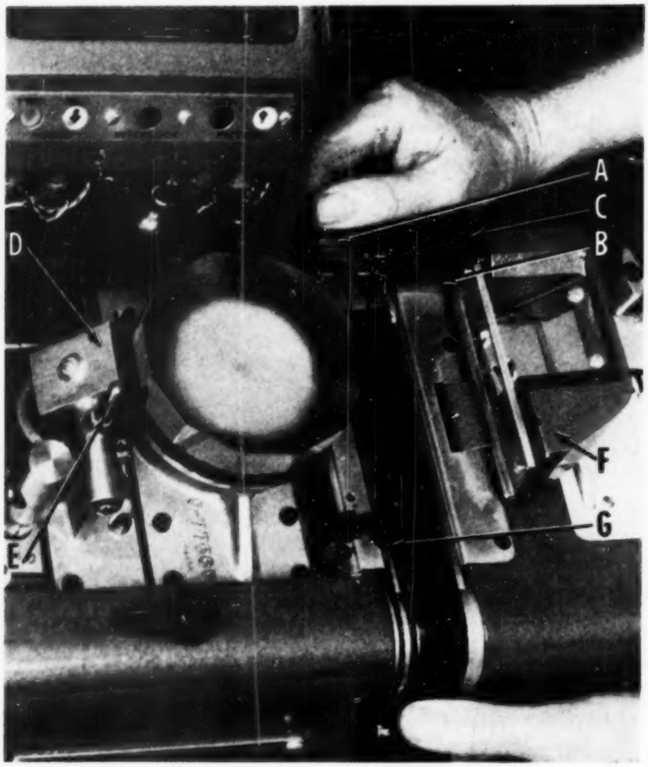

Fig. 6. Close-up of picture film trap, showing method of threading film.

worm and gear H and G and the manual indexed control I. The pair of epicyclic gears have different gear ratios and in consequence, when the carrier is rotated about the jack-shaft center, the sound film is advanced or retarded with respect to the picture film.

Film Traps

Figure 6 is a view of the picture-film trap and gate and illustrates the method of threading. The film is held between the two hands and laid in the film trap under light tension to sense the engagement of the sprocket teeth with the holes. The thumb is then in a position to press the film down and operate a trigger button shown at A which causes two film-retaining slides to move over the edges of the sprockets and retain the film in engagement. One of these slides may be seen as B. Closing the gate F completes the threading. The latter is held closed by the lever G, which may be operated at any time to release the gate but not the film-retaining slides. This permits ready access to the full area of the film for marking without losing synchronization. Depressing the upper lever C opens the gate and releases the film simultaneously.

For synchronizing purposes, the handwheel is turned to index any one frame with a reference arrow located in the

center of the picture aperture, the arrow also being projected onto the viewing screen. The picture gate contains only a mirror for bending the light path. As shown by Fig. 3, the single screw A permits removal of the entire lamp mounting assembly, and the screw B releases the complete condenser and heat filter assembly for cleaning.

Sound Reproduction

The quality of reproduced sound is considerably better from the standpoint of frequency characteristic, signal-to-noise ratio and flutter than that which is usually associated with film-editing devices. The optical-scanning system is substantially the same as that in general use in theater reproducers. The magnetic head is a conventional commercial type. A four-stage amplifier is used for photographic sound reproduction and one additional stage is connected for magnetic reproduction with magnetic-reproducing equalization provided. The photographic input circuit contains a narrow dip filter tuned to 120 cycles to attenuate the light modulation resulting from operating the sound lamp on a-c. This feature combined with the relatively high thermal inertia of the 7.5-amp lamp gives a saitsfactory signal-to-noise ratio for this use. A tone control is provided on the amplifier and its knob appears through the top of the equipment box. An output jack is also provided at this point to plug in an extension speaker to be used with wall projection if desired.

Motors

The picture film is driven by a variable-speed torque motor which in combination with the foot-pedal resistance control is capable of driving the film at variable speeds from essentially standstill to double normal speed and is instantly reversible while running.

The sound film is driven by an induction motor, which is substantially constant speed, and is equipped with an electrical brake. A circuit is arranged to charge a condenser with rectified a-c from the line. When the foot pedal is released, back contacts on the switch connect the charged condenser to a relay coil and operate it for a short interval which is determined by the discharge rate of the condenser and the associated circuit. The relay momentarily connects a second charged condenser across the field winding of the motor, and, depending on the adjustment of a current-limiting resistor, the motor can be stopped within two picture frames. This type of braking is fully automatic and has the advantage of having no braking torque applied when the machine is turned by the handwheel.

In conclusion, it is felt that the Westrex Editer will fill a long-existing need of the motion-picture industry for modernized film-editing facilities with increased efficiency and improved convenience in operation.

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A Nonintermittent Photomagnetic Sound Film Editor

By W. R. HICKS

The editing of magnetic sound tracks by visual and aural methods has become increasingly important because of the rapid adoption of the magnetic system by the industry, both for primary recordings and theater release. Three-dimensional theatrical and multicamera television films have also stressed the need for editors which show more than one picture. A solution is suggested for these problems and a system of electronic editing is proposed, leading to an enlargement of editing processes to include sound recording, re-recording and dubbing, formerly limited to the sound studio.

The development of magnetic sound recording has greatly influenced the technical handling and treatment of sound tracks following the general acceptance of the magnetic system by motion-picture producers. Initially, the magnetic track was approved for primary recordings because of its high signal-to-noise ratio, low distortion and ease of playback. But invisible magnetic tracks were impossible to edit by conventional sight methods, and magnetic recording required transfer to photographic tracks for subsequent editing, mixing and release on photographic equipment. Various systems for visualizing the recorded magnetic track were tested to facilitate direct track editing. Some early methods featured the use of magnetic inks and wet solutions containing carbonyl iron, but these were in general awkward and sometimes messy and were superseded by auxiliary visual track systems, including a combination of parallel magnetic and photographic sound tracks or companion inked tracks traced directly on the magnetic film, this system being known as modulation writing.

With these aids the motion-picture editor now cuts and assembles magnetic tracks in much the same manner as photographic tracks, on familiar equipment adapted for magnetic-track scanning. Editing by sight methods, he depends upon his magnifying glass or optical loop, but he must still check finished cuts audibly on machines with low-quality sound-reproducing elements and high flutter and mechanical noise. The word endings of a photographic track or visualized magnetic sound track are not easily seen when the frequency is high and modulation low. Cutting errors often result which are difficult to detect audibly on small loudspeakers and amplifiers of limited frequency range and when mechanical noise reduces intelligibility. Later listening under the high-quality conditions of a mixing room or theater often discloses missing

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"ess" sounds, faultily de-blooped splices and unwanted stage background noise. In many cases, after preliminary rehearsal a reel with its multiple sound tracks must be returned to the cutting room for further work.

For critical listening the editor needs equipment with performance at least comparable to the machine and electronic elements of the mixing room. This is especially true when auxiliary sight-cutting tracks are unavailable because of added cost, and the invisible magnetic track must be edited directly by listening methods alone.

The editor described has been designed to meet these requirements. Mechanical noise has been reduced by minimizing gear components. Uniform film motion with low flutter is stressed, and the reproducing amplifier, power supply and loudspeaker system are

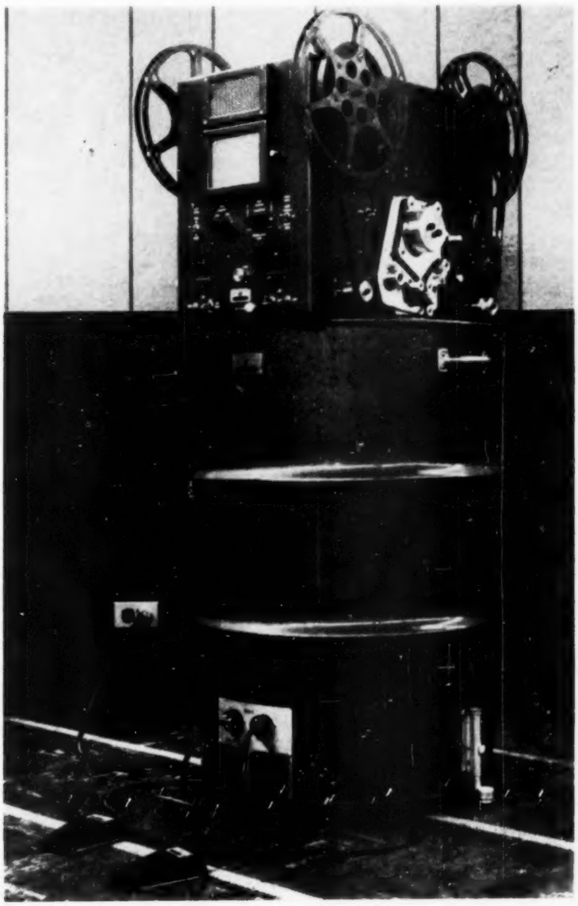

Fig. 1. Editor twin with sound side threaded and mounted on barrel pedestal with foot-treadle and touch-plate controls.

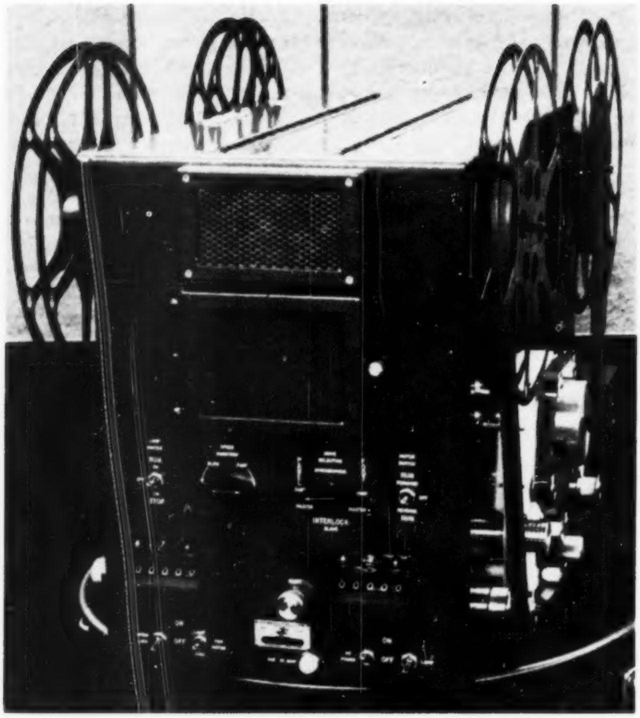

Fig. 2. Editor twin showing sound side threaded, footage counters, motor and lamp controls, screen and loudspeaker frames.

engineered to equal the performance of similar units in a studio equipment group. Film scratches, abrasions and perforation deformation are minimized by the wide use of fluoroethylene plastic in rollers and shoes, combined with a dependable, nonintermittent system of picture projection. A welded metal case houses all drive components and electronic equipment and encloses the picture-projection path. Operating controls are grouped on the front of the case which contains a rear-vision screen, loudspeaker and footage counters. The case sides serve as mounting walls for separate work-print and sound-track film transports complete with torque-motor driven reel spindles and cast assemblies for the alignment of sprockets, pad rollers, photographic and magnetic sound-scanning units and the picture-projection and imaging optical systems. Coupling knobs on each side select either or both transports, with permanently linked footage counters for record purposes. In addition, a compact assembly on the sound side facilitates aural magnetic-track editing.

Dynamic Scanning

Magnetic tracks are normally reproduced or scanned by running film at a uniform speed past a stationary magnetic head in contact with the magnetic coating. Track scanning is also feasible if the film is held stationary and the head moved while maintaining contact with the coating. This method

is used in the editor dynascanner, which employs a magnetic head rotating within a film-wrapped drum and contacting the magnetic coating along a film length corresponding to from two to five spoken words. Twin guide rollers determine the drum wrap which is an integral part of the film path. Head rotation is controlled by a small synchronous drive motor operated by a switch on the control panel.

In operation, a magnetic track roll is threaded on the sound side and run against the work print with the scanner drum rotating and the head stationary. Word endings are located by stopping the machine, decoupling the sound side and powering the head drive motor. The drum is now stationary and the head rotates continuously, reproducing only the portion of the magnetic track which wraps the drum. A knob on the film sprocket is then turned slowly to position the exact word end at a point on the drum where the moving head leaves the coating. Engraved frame lines on the drum face assist the editor in marking the film for future cutting. Word beginnings are found and marked in the same manner.

Recording and Copying

The producer who cannot assume the risk of cutting an irreplaceable original magnetic sound track must re-record, or copy it. The copying process requires a magnetic reproducing or "dubbing" machine, an electronic audio-control channel, a magnetic recording machine and a monitor system. The producer usually rents the facilities of a sound-service studio and pays rental fees plus film costs for the copying service. If he uses the auxiliary sight-cutting track method he finds his track-cutting costs rising sharply above the standard photographic sound work-print costs which were part of his earlier budgets.

Should he decide to do his own magnetic-track copying and edit the copied track by dynamic-scanning methods without visual aids, he must have equipment which technically approaches the quality of units in the service studio. This equipment requisite, with one addition, is supplied by the basic editor twin, which has been designed to operate with a small, complementary console recording amplifier (Fig. 3), to perform a wide range of recording and re-recording operations.

Fig. 3. Mite recording amplifier showing control panel and input and output receptacles.

The console amplifier is housed in an aluminum case with detachable cover, with carrying handle and neck strap for transport. Power is supplied from dry batteries of the portable type but large enough for operation over an extended period. The amplifier gain is in excess of 100 db, and contains a high-frequency oscillator and mixer stage for direct cabling to a magnetic recording head. Output cable lengths up to 25 ft in length are practicable, as the bias voltage is read on the panel volume-indicator meter and is adjustable from a panel knob. Input impedances of 50, 250 and 500 ohm are available for low-impedance microphone use. A record-re-record switch on the panel is provided for microphone recordings or editor copying work. In the re-record position only the output stage and bias oscillator are powered. A second record-rehearse switch powers the oscillator for extended rehearsal periods, and also disconnects the volume indicator. Oscillator tank and coupling coils are of high Q, mounted in a shielded case containing tunable capacitors. Recordings cannot be made with the switch in the rehearsal position, and the operator is always certain recording is taking place when the volume indicator is operating. Batteries are accessible by removing a screw and folding back half of the amplifier control panel. Amplifier response is flat to 9000 cycles/sec and intermodulation products are less than 1%.

The case cover contains a crystal earwig monitor unit with cord and jack, microphone and output cables, microphone, desk stand and a tripod capable of elevating the microphone 7 ft above floor level. The tripod is also adaptable for use as a hand-held microphone extension pole 8 ft in length. The complete case is 10.5 in. long, 3 in. wide and 8.5 in. high, and weighs 10.25 lb.

There are many uses for a recording editor and console which do not demand personnel with engineering experience. The film editor employs the magnetic track for voice comments and advice to the producer at a rough work-print showing, to the composer who will write a score, or to the special-effects department for spotting wipes and dissolves. With even reasonable care it is a simple matter to record a narration track, and a variety of sound effects can be made, synchronized with work-print action, if desired. The console amplifier suffices for this work, and is suitable for basic stage-dialogue recording.

More complicated mixing consoles are necessary for involved procedures, as are additional sound reproducers. Matching sound twins are provided for this purpose, serving as additional editing heads in the cutting room and as multiple copying machines when 16mm magnetic-striped release prints are needed in quantity. Each machine is equipped with the synchronous-interlock variable-speed motor developed especially for the editor twin, insuring frame-for-frame synchronism between all machines without additional distributor or master control equipment. Any combination of 16mm, 17.5mm and 35mm tracks is possible for multireel editing and synchronizing.

When a sound twin is used in interlock with a twin editor many unusual combinations are available for projection, recording and re-recording. One of the most interesting from the standpoint of the film cutter and sound engineer is the possibility of "cutting" sound tracks electronically, without having recourse to the scissors or film splicer. An entire dialogue reel can be assembled by matching the opening picture scene with its associated photographic or magnetic sound track on the editor, followed by re-running and re-recording to a separate magnetic film on the sound twin, used as a recorder. Following picture scenes are cut and spliced as desired, then matched with sound tracks which are reproduced on the editor

and recorded magnetically on the sound element. Previously recorded tracks are played back with previously cut and spliced picture scenes of the roll under assembly, and the following track is reproduced, recorded and monitored instantaneously when the rehearse-record switch on the control console is operated. In this manner original magnetic sound tracks can be preserved on the same film roll on which they were originally recorded.

Such a system is especially valuable for the assembly of sound tracks which have been recorded against picture loops in the well-known dubbing, or foreign-version scoring process. The illuminated footage counter with frame wheel is an accurate manual-switching reference, but sound sequences separated by five frames may be re-recorded automatically when a splice-actuated microswitch on the editor picture side is used. This switch controls a speech relay of the sequence type, which also stops the recording when the scene ends. All tracks are reproduced by the standard editor amplifiers, and the auxiliary recording console connects directly to the erase and record heads of the sound twin during recording.

Editor Amplifier

A fully equipped editor twin is furnished with separate photographic and magnetic scanning elements on the sound and picture sides. The head and photocell leads connect to inner case receptacles mating with connectors on the plug-in amplifier chassis. The chassis and amplifier control panel are combined in an assembly for case closure, with jacks, volume controls, switches and fuses appearing on the panel. Power and motor-control receptacles are divorced from the amplifier and mounted on the rear of the case above the amplifier panel. Four two-stage preamplifiers, each with low- and high-frequency compensating feedback loops, are used to amplify the output signal of the magnetic heads and photocells. Individual potentiometers control loudspeaker editing volume, or track levels during re-recording. Photocell volume controls are combined with exciter lamp switches; lamp currents are not changed when one or both lamps are used.

Closed circuit jacks on the panel connect the magnetic heads to the preamplifier inputs, so that either head may be cabled to the output of the recording console by a phone plug and cord. Separate 8-ohm, 500-ohm and headset jacks terminate the amplifier output. The 500-ohm circuit is used for re-recording with the console and for connection to the power amplifier and loudspeaker of monitor or review-room equipment. The 8-ohm jack normals to the speaker in the editor case and is used for external connection to a larger loudspeaker. Provision is made for the use of a headset when circumstances prohibit loudspeaker operation in a cutting room where several machines are active. The amplifier tube heaters as well as the exciter lamps are supplied with d-c from separate rectifier systems. The amplifier plate rectifier tube and filter components are on the chassis but the power transformers, selenium stacks and low-voltage filter components are remotely mounted in the editor case, connected to the amplifier through the mating receptacles. A neon pilot lamp on the panel lights to indicate failure of the amplifier fuse.

At the 2-w rated output, a signal-to-noise ratio in excess of 55 db is achieved, with intermodulation products of less than 1%. Amplifier gain is 105 db with a flat response from 30 to 10,000 cycles/sec. Output power is more than ample for operation of the case loudspeaker, and is sufficiently high to drive a remote speaker of larger size at sound levels associated with medium review rooms.

Lower-performance amplifiers are also furnished with integral power supplies.

Frequency response and distortion are similar but signal-to-noise ratio is limited to 35 to 40 db. Noise ratings include magnetic heads connected to the amplifier inputs.

Design Elements

The exciter lamp, sound optical system and magnetic head needed for photographic and magnetic track reproducing have been combined in a compact assembly with all requisite focusing and adjustment controls. The prefocused exciter-lamp mount includes a push button which relieves spring pressure for replacement. A slitless lens system has accurate azimuth adjusting screws, and the entire assembly is movable micrometrically for focus and track location. The emulsion planes of standard and nonstandard prints are selected quickly by a limited-throw angle lever.

A subassembly mounts the retractable magnetic head, with adjustments for azimuth, track location, tangent positioning and film-plane contact. The head is controlled by a detented selector knob on the assembly-casting cover. A single knurled screw fastens the cover, which is grilled for lamp ventilation.

In combination with a photoemissive cell on the film-transport assembly and the compensated preamplifier the photographic scanning system reproduces 16mm tracks with a range of 40 to 7000 cycles/sec without deviation. The magnetic scanning head and its associated preamplifier reproduce magnetic sound tracks faithfully over a range of 40 to 9500 cycles/sec. A complete photomagnetic scanner assembly is furnished on the sound and picture sides of a fully equipped editor twin.

Projection and Imaging Optics. A separate assembly houses the projection lamp, reflector, heat absorbing phosphate and aspheric-condenser lens for projection. The standard 100-w prefocused lamp may be replaced by 200- and 300-w lamps for large-screen wall projection. The aspheric-condenser element images the lamp filament in the aperture of the objective lens. Two first-surface mirrors in slab mountings reflect the illuminated film frame to a rear-vision daylight screen 5 × 7.5 in. A 90° rotation of the initial mirror reflects the picture at right angles to a wall screen. All glass parts are accessible for cleaning.

Nonintermittent Picture Projection. The continuous projection of a motion-picture frame sequence with a multifaceted prism has depended on the principle of control of prism rotation by the moving film, and has demanded gearing of extreme precision. The editor operates with a conventional twelve-sided prism, gear connected to two film-registering sprockets. A Gilmer pulley on the prism shaft is connected by a timing belt to a low-speed motor-driven pulley, and a combination aperture plate and pressure shoe produces tension in the film which cancels gear backlash. The film is side guided at the shoe to eliminate weave.

Drive Motor. For flexible operation, either alone or with other units, a single drive motor was developed for the editor by W. R. Turner. The motor runs synchronously at 1800 rpm, variably over a range of 0 to 3400 rpm and in synchronous interlock with the motors of other machines. Forward and reverse operation is controlled manually by a toggle switch on the front panel or by treadle switches or foot touch plates mounted in several types of pedestal bases.

Because of the positive nature of the interlock design all machines can be started, stopped and restarted without loss of synchronism. Machines of various types may thus be grouped for operation without dependence on coupling shafts, common bases or tables. The motor is powered from standard 110/115-v, 1-phase, 60-cycle mains, and is also supplied for 50-cycle use.

Decoupler Knobs and Footage Counters. The picture and sound sides may be

run in mechanical lock or individually, by operation of the decoupler knobs. A slight pull out and 90° twist disconnects the film-transport sprocket shaft from the low-speed motor shaft, allowing the sprocket knob to be turned freely for film movement. Cove-mounted footage counters are permanently connected to the sprocket shafts of the sound and picture drives, operating independently of the decouplers. The counters have four digit wheels and a forty-frame wheel, and are illuminated.

Reel Spindles and Controls. The spindle torque motors are powered by the action of lift rollers on the case sides. After threading, the operator rotates the film reels manually to eliminate slack, raising the lift rollers. As the rollers lift, microswitches supply power to the spindle motors, maintaining the film to and from the sprockets under tension. When film runs out the falling lift rollers disconnect the motors and the reels come to rest. The lift rollers are also used for high-speed rewinding and winding under the control of a panel toggle switch. Each motor is cradled in a bracket for axial tilting against a balance spring. A weight increase of the reel due to added film lowers the motor position and actuates a microswitch on the bracket. Spindle torque is influenced by two capacitors, selected by the switch. The motors are not connected with the wiring of the drive motor, and do not operate when hand-held rolls are threaded. The spindles accept standard 400-, 800- and 1200-ft reels.

Pedestals. Hand-held rolls exit from the machine directly downward to eliminate lengthy guide chutes. Picture and track takes double wound on a single roll are easily fanned out and side threaded, dropping into twin cotton barrel liners in the base. The barrel bottom contains five single-ball antifriction casters for floor clearance, movement and rotation. A circular floor mat with double race rails may be used under the barrel for rapid center swiveling. Handles and foot-operated locking pads are standard equipment.

A metal-case pedestal matching the dimensions of the editor base is also supplied with a tilting top and formed rods for side cotton bags. Both bases are fitted with foot touch plates vertically mounted for start–stop and forward–reverse motor control. Receptacles paralleling the touch-plate switches are provided for connecting sloping foot treadles or hand-held pear-button switches. The base design accepts individual splicers on folding drop leaves for direct film cutting without removal to a splicing table.

Rollers and Shoes. The tetrafluoroethylene resin (Teflon) used in the construction of the rollers and shoes possesses several remarkable properties. It has high adhesive resistance, with a waxy surface on which nothing will stick. It is highly inert chemically. Machined in roller form it repels dirt particles that might scratch film emulsions. In shoe form it safely changes film direction without scoring or unusual deformation. It is nonflammable and has a service range of from minus 320 to plus 500 F. The Teflon rollers used are bushed with oilless bearings and have pressed anodized Duralumin side flanges.

The editor case design and picture-projection system permit the use of either side, or both, for picture-film transport and projection. By increasing the case width, two picture screens may be installed for the simultaneous projection of long shot and close-up camera takes. The production of films for television stresses the two-camera technique, and the editing of both films on a common machine with side-by-side pictures aids the cutting process. An interlocked sound twin is used for sound-track matching.

The double-side picture-projection system has also lessened the difficulty of editing and assembling three-dimensional 35mm films. A single screen is used with the projection throws super-

imposed, and the screen is viewed conventionally through polarized glasses or through an extension jib-mounted polarized septum viewer. An interlocked sound twin for three-track magnetic-track reproduction is supplied, with three loudspeakers in a composite wall baffle. The review of films with high aspect ratios requires only the correct aperture and the addition of any specified magnetic-head type with multiple amplifiers and speakers.

Magnetic sound tracks were once considered valuable only as a preproduction aid. Their eventual use on release prints, either 16mm or 35mm, was discounted because of the vast problem of equipment modification and replacement. It is now apparent that this problem may be solved in the very near future. Magnetic projectors for reproducing 16mm magnetic edge-striped prints are already in wide use. Multiple magnetic stripes on 35mm prints are featured by CinemaScope and similar systems and theaters are now being rapidly equipped to show these films. Cinerama has demonstrated the practicability of recording and playing back with six magnetic sound tracks in a system which has discarded photographic sound completely. Three-dimensional films have been released accompanied by separate magnetic sound rolls using three tracks which require a magnetic reproducing machine interlocked with a projector in the theater booth. A large number of theaters are now making such installations. Television networks depend upon an interlocked magnetic sound reproducer for kinescoped programming and will undoubtedly adopt the magnetic-striped release print at a later date.

Because of its adaptability to the many phases of picture and sound editing, sound recording, re-recording and magnetic-print production, the editor and its associated units would appear to merit the close study of motion-picture producers.

Acknowledgments

The author sincerely appreciates the assistance of G. J. Badgley, U.S. Naval Photographic Center, Dr. E. C. Fritts of the Eastman Kodak Co., and Dr. Franz Ehrenhaft of Scanoptic, Inc.

Discussion

George Lewin (Signal Corps Photographic Center): Could you clarify the function of the rotating head on the side? Is that for repeating a word for spotting purposes?

Mr. Hicks: We are stressing the importance of determining precisely the beginning and end of words. Visualizing devices such as modulation writing and combinations of magnetic stripes with photographic sound tracks do not always provide a definite indication of word endings visually, as most endings are low in level, high in frequency or a combination of both. These sounds are very difficult to see, and it is not unusual for the film editor to cut a track and lose an "ess" or a similar sound. He also often fails to see or hear low-level modulations which are a part of stage background sounds and leaves them in the track. These must then be further edited after they have been noticed during a rehearsal mixing session.

With the dynamic scanner the film stands still while the head is rotated. The head reproduces only the words or parts of words which wrap the scanner drum, and film on the drum can be shifted by the editor until the word beginning or end is heard. After the exact spot is determined the film is marked and cut in the usual way. The drum wrap allows from two to five words to be scanned, depending on the speed of the original speech. Scanning sound tracks in this manner helps the film editor considerably, especially when high-quality sound reproduction is combined with low machine noise.

Automatic Film Splicer

By A. V. JIROUCH

An automatic film splicer is described in which an accurate join is obtained rapidly by the movement of two levers. The essential requirements of a modern splicer and their practical fulfillment are discussed.

PERHAPS BECAUSE a splice is such a small thing very little attention has been given to the matter of splicing in the motion-picture industry. Improvements have been suggested from time to time in new patents and in the technical literature, but few have actually been put into effect. The result is that in spite of the vast progress made in the industry generally many of the same splicing problems that were experienced 45 years ago are still being encountered today. The work of the SMPE Subcommittee on 16mm Film Splices[1] may be considered as the first serious discussion of the problems in this field with practical suggestions for improvement.

Work was begun in 1945 to design a splicing machine which would cut, scrape and apply cement and appropriate pressure through a limited number of operations to ensure a perfect splice without dependence on the skill of the operator. The first prototype was an electrically driven machine.

Scraping. Different types of scraping tools, both static and rotating, were tested, the surface of each scrape was photographed and solubility tests made on different bases. During the progress of the work these tests gave good experience with different mixtures of practically all known solvents. Samples of the splices made were stored and later gave valuable information with respect to ageing of different types of film base and durability of joins.

As the number of samples increased it became more and more evident that the best results were achieved with tools removing the emulsion, substratum and skin of the base with one stroke, leaving the base rough, clean and open for penetration of solvents. It was not until six prototypes were built that it was possible to solve the question of uniform depth of scrape. This was achieved through a combination of specially shaped cutting tools, each one removing a part of the emulsion only (see Fig. 1 at E 41, 42).

To determine the optimum width of join about 2500 different samples were used to show that joins ranging from

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Presented on October 7, 1952, at the Society's Convention at Washington, D.C., by A. V. Jirouch, Cine Television Equipment (Overseas) Ltd., 317 Belle Grove Rd., Welling, Kent, England (paper read by Harry Teitelbaum, Hollywood Film Co., 5446 Carlton Way, Hollywood 27, Calif.).
(This paper was received October 7, 1952, and in revised form March 16, 1953.)

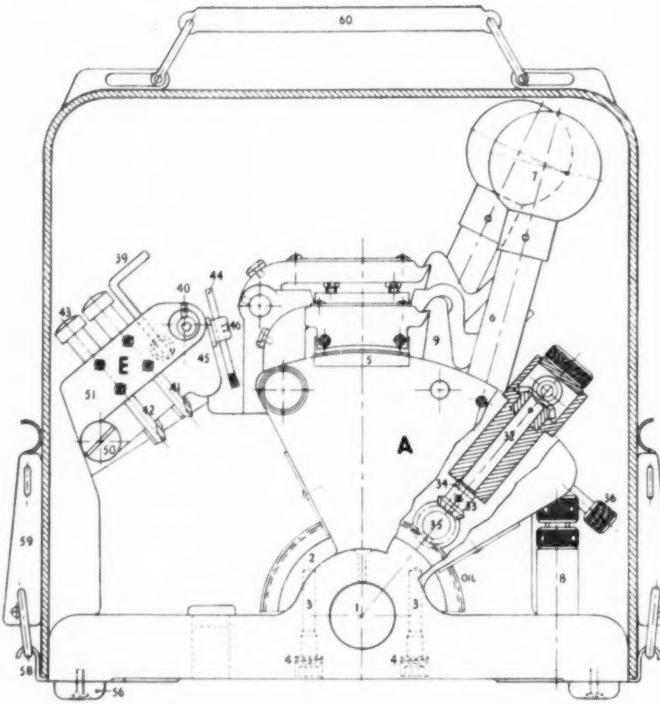


Figure 1

45 to 70 thousandths of an inch had the same tensile strength. It was not difficult to produce an overlap 20 thousandths of an inch wide with a tensile strength greater than that of the base itself. It is not proposed at this time to discuss the different standards and widths of overlap used at present, but further data will be published on the durability of joins of different widths of overlap after completion of full-scale tests.

The application of cement. Experience gained during the tests just mentioned showed that superior results were obtained when the cement was applied on the glossy surface of the base, instead of on the scraped area (see Fig. 3 at D, A 52, B 19).

It was found that even better results could be obtained by applying the cement with a roller applicator of special surface and tension (see Fig. 3 at 37, 38). The repeated passage of this roller across the surface of the film base not only applied the correct quantity of cement but also increased the penetration of solvents by agitation of the cement layer. In this way the base was dissolved to a sufficient depth to ensure a perfect weld. This principle of application has also solved the difficulty of anti-halo coating on several materials so that separate scraping of the coating is no longer required.

Controlled pressure. Throughout the years various improvements have been made, but pressure control has become more and more important. Much attention was therefore given to the

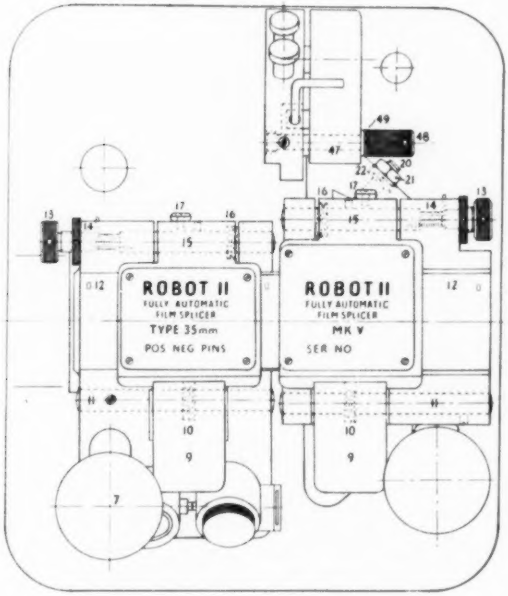


Figure 2

cam-locking mechanism and the diagram (see Fig. 3 at C 28, 53, etc.) shows that the actual pressure is applied at the moment when the cam is locked.

Suitable universal cement. The general use of safety base has introduced certain difficulties with regard to film cement. Cellulose acetate is a linear high polymer and displays the remarkable properties of a long-chain molecule, but the general solubility is somewhat more limited than that of cellulose nitrate. The fast mechanical operations of the machine permitted the use of low-viscosity solvents of balanced evaporation time. In this way no additional heating is required and the cement maintains its characteristics throughout the application and storage.

Tests were made to prove that evaporation of solvents and loss of plasticizers from the base do not affect the durability of a splice made with this cement in conjunction with the mechanical properties and speed of this machine. Several loops each with six joins were incubated by Kodak Limited, Harrow, England, and the effective ageing was observed by measuring the loss of solvents. All samples, even when prepared under different working conditions (room temperature and relative humidity), have shown greater tensile strength than the base itself. Seventeen of these samples were presented with the paper and it was found impossible to separate the splices by any means.

Details of operation. It is well known that a good scrape with poor application of cement, uneven pressure or an unsatisfactory quality of cement will never give a reliable splice. And, of course, a poor splice is obtained with any combination of these factors.

Recognizing the problems, all the above considerations were considered in designing the Robot Automatic Film Splicer which integrates the scraping,

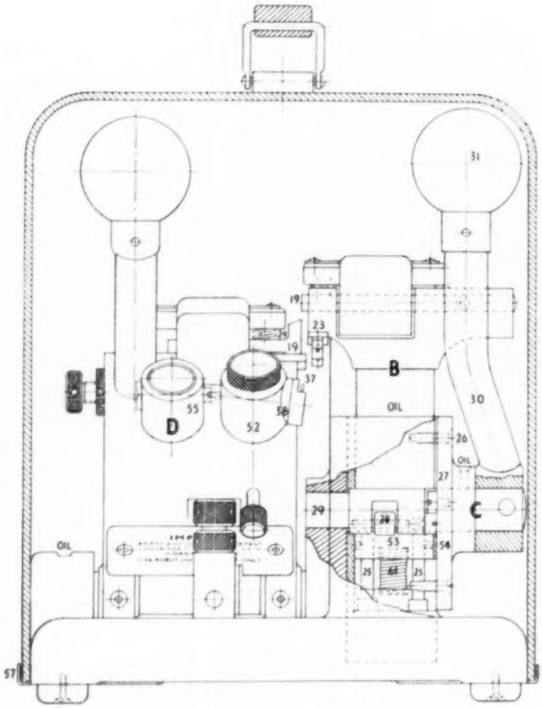


Figure 3

the application of cement and control of pressure, thereby providing the perfect splice on all types of film base presently in use. It is simple to operate and the influence of the human element is limited to the movement of the two levers only.

The forward and backward movement of the rocking block (Fig. 1 at A) scrapes the emulsion to uniform depth and at the same time applies cement to the opposite part of the film. The up-and-down movement of the right sliding block (Fig. 3 at B) cuts both ends of the film squarely and applies the pressure.

The machine is sturdily built, all important parts being made of stainless steel, ground and lapped, and both rocking and sliding movements are compensated for wear by spring-loaded tension (see Fig. 1 at A 1, A 2; Fig. 2 at 20, 21, 22). The three-point register pins allow both negative and positive film to be spliced without adjustment being required.

The cement tank holds sufficient cement for approximately 50 splices and a special adaptor can be fitted so that the machine can be operated all day without refilling.

The scraping tools of high-speed steel will never require replacement and seldom require sharpening. Machines in practical use for 36 months far exceeded the originally claimed 50,000 operations without resharpening.

The Robot II weighs 38 lb and is equipped with a metal dust-proof cover (see Fig. 1 at 58, 59, 60) and can be operated anywhere without being attached to the bench (see Fig. 1 at 61,

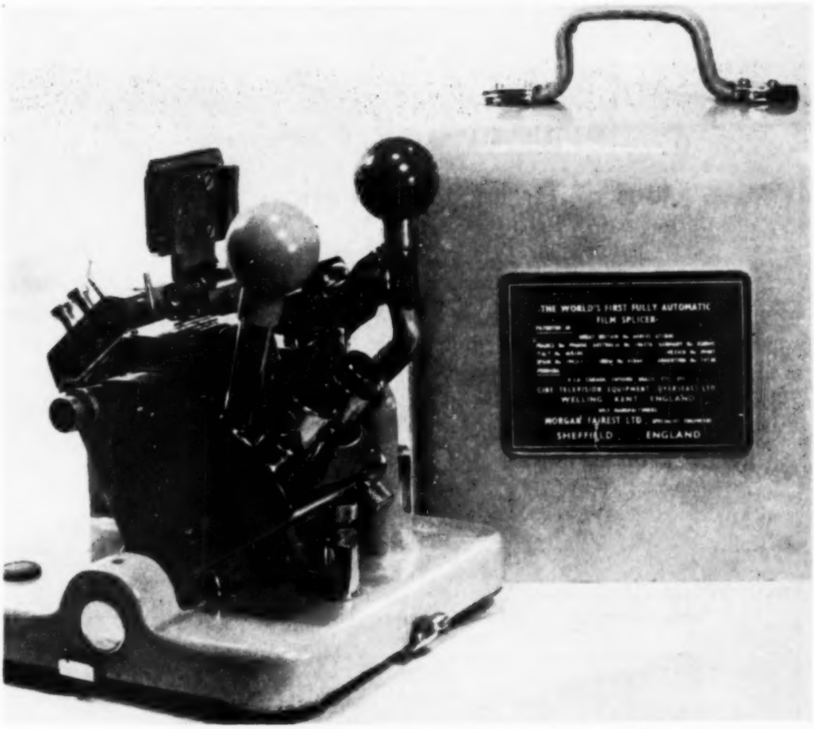


Fig. 4. The Robot II Splicer—Mark V 35mm model.

56). Its dimensions are $7\frac{1}{4} \times 8\frac{3}{4} \times 6\frac{1}{2}$ in.

Acknowledgment. The author would like to express his appreciation to Messrs. Kodak Limited, Harrow, England, for their cooperation and assistance in the preparation of samples.

References

1. Report of the Subcommittee on 16mm Film Splices, *SMPE, 47:* 1–11, July 1946.
2. Pierre Jacquin, "Collures et colleuses," *La Technique Cinématographique*, Sept. 1948.

Revision — PH22.11 – 1953
16mm Motion Picture Projection Reels

THIS AMERICAN STANDARD was republished in the September 1952 *Journal* on pp. 233–237. Dimension S was incorrectly designated as an inside dimension in the drawing on p. 1 of the Standard (*Journal* p. 234). The complete Standard has been processed as a revision and the full Standard, ASA's PH22.11-1953 (officially a revision of PH22.11-1952), is published on the following pages.

American Standard
for
16-Millimeter Motion Picture Projection Reels

ASA
Reg. U. S. Pat. Off.
PH22.11-1953
Revision of
Z22.11-1941
and
Z52.33-1945
*UDC 778.55

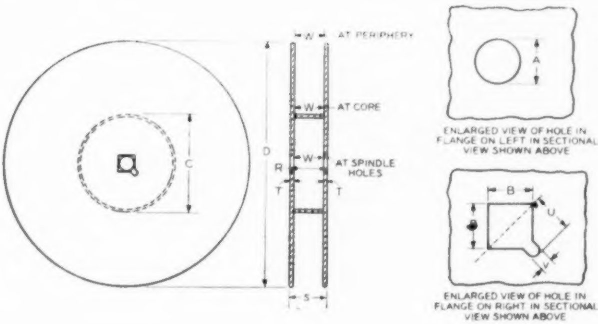


Table 1 See page 3 for notes.

Dimension	Inches	Millimeters
A	0.319 $^{+0.000}_{-0.003}$	8.10 $^{+0.00}_{-0.08}$
B	0.319 $^{+0.000}_{-0.003}$	8.10 $^{+0.00}_{-0.08}$
R[1]	0.790 maximum	20.06 maximum
S[2] (including flared, rolled, or beveled edges, if any)	0.962 maximum	24.43 maximum
T (adjacent to spindle)	0.027 minimum 0.066 maximum	0.69 minimum 1.68 maximum
U	0.312 ±0.016	7.92 ±0.41
V	0.125 $^{+0.005}_{-0.000}$	3.18 $^{+0.13}_{-0.00}$
W, at periphery[3]	0.660 $^{+0.045}_{-0.025}$	16.76 $^{+1.14}_{-0.64}$
at core[4]	0.660 ±0.010	16.76 ±0.25
at spindle holes	0.660 ±0.015	16.76 ±0.38
Flange and core concentricity[5]	±0.031	±0.79

Approved September 11, 1953, by the American Standards Association, Incorporated
Sponsor: Society of Motion Picture and Television Engineers

*Universal Decimal Classification

16-Millimeter Motion Picture Projection Reels

ASA Reg. U. S. Pat. Off.

PH22.11-1953

Table 2

Capacity	Dimension	Inches	Millimeters	Capacity	Dimension	Inches	Millimeters
200 feet[6] (61 meters)	D, nominal	5.000	127.00	1200 feet (366 meters)	D, nominal	12.250	311.15
	maximum	5.031	127.79		maximum	12.250	311.15
	minimum	5.000	127.00		minimum	12.125*	307.98*
	C, nominal	1.750	44.45		C, nominal	4.875	123.83
	maximum	2.000*	50.80*		maximum	4.875	123.83
	minimum	1.750	44.45		minimum	4.625*	117.48*
	Lateral runout,[7] maximum	0.057	1.45		Lateral runout,[7] maximum	0.140	3.56
400 feet[6] (122 meters)	D, nominal	7.000	177.80	1600 feet (488 meters)	D, nominal	13.750	349.25
	maximum	7.031	178.59		maximum	14.000*	355.60*
	minimum	7.000	177.80		minimum	13.750	349.25
	C, nominal	2.500	63.50		C, nominal	4.875	123.83
	maximum	2.500	63.50		maximum	4.875	123.83
	minimum	1.750*	44.45*		minimum	4.625*	117.48*
	Lateral runout,[7] maximum	0.080	2.03		Lateral runout,[7] maximum	0.160	4.06
800 feet (244 meters)	D, nominal	10.500	266.70	2000 feet (610 meters)	D, nominal	15.000	381.00
	maximum	10.531	267.49		maximum	15.031	381.79
	minimum	10.500	266.70		minimum	15.000	381.00
	C, nominal	4.875	123.83		C, nominal	4.625	117.48
	maximum	4.875	123.83		maximum	4.875	123.83
	minimum	4.500*	114.30*		minimum	4.625	117.48
	Lateral runout,[7] maximum	0.120	3.05		Lateral runout,[7] maximum	0.171	4.34

*When new reels are designed or when new tools are made for present reels, the cores and flanges should be made to conform, as closely as practicable, to the nominal values in the above table. It is hoped that in some future revision of this standard the asterisked values may be omitted.

Note 1: The outer surfaces of the flanges shall be flat out to a diameter of at least 1.250 inches.

Note 2: Rivets or other fastening members shall not extend beyond the outside surfaces of the flanges more than 1/32 inch (0.79 millimeter) and shall not extend beyond the over-all thickness indicated by dimension S.

Note 3: Except at embossings, rolled edges, and rounded corners, the limits shown here shall not be exceeded at the periphery of the flanges, nor at any other distance from the center of the reel.

Note 4: If spring fingers are used to engage the edges of the film, dimension W shall be measured between the fingers when they are pressed outward to the limit of their operating range.

Note 5: This concentricity is with respect to the center line of the hole for the spindles.

Note 6: This reel should not be used as a take-up reel on a sound projector unless there is special provision to keep the take-up tension within the desirable range of 1½ to 5 ounces.

Note 7: Lateral runout is the maximum excursion of any point on the flange from the intended plane of rotation of that point when the reel is rotated on an accurate, tightly fitted shaft.

Appendix

(This Appendix is not a part of the American Standard for 16-Millimeter Motion Picture Projection Reels, PH22.11-1952.)

Dimensions A and B were chosen to give sufficient clearance between the reels and the largest spindles normally used on 16-millimeter projectors. While some users prefer a square hole in both flanges for laboratory work, it is recommended that such reels be obtained on special order. If both flanges have square holes, and if the respective sides of the squares are parallel, the reel will not be suitable for use on some spindles. This is true if the spindle has a shoulder against which the outer flange is stopped for lateral positioning of the reel. But the objection does not apply if the two squares are oriented so that their respective sides are at an angle.

For regular projection, however, a reel with a round hole in one flange is generally preferred. With it the projectionist can tell at a glance whether or not the film needs rewinding. Furthermore, this type of reel helps the projectionist place the film correctly on the projector and thread it so that the picture is properly oriented with respect to rights and lefts.

The nominal value for W was chosen to provide proper lateral clearance for the film, which has a maximum width of 0.630 inch. Yet the channel is narrow enough so that the film cannot wander laterally too much as it is coiled; if the channel is too wide, it is likely to cause loose winding and excessively large rolls. The tolerances for W vary. At the core they are least because it is possible to control the distance fairly easily in that zone. At the holes for the spindles they are somewhat larger to allow for slight buckling of the flanges between the core and the holes. At the periphery the tolerances are still greater because it is difficult to maintain the distance with such accuracy.

Minimum and maximum values for T, the thickness of the flanges, were chosen to permit the use of various materials.

The opening in the corner of the square hole, to which dimensions U and V apply, is provided for the spindles of 35-millimeter rewinds, which are used in some laboratories.

D, the outside diameter of the flanges, was made as large as permitted by past practice in the design of projectors, containers for the reels, rewinds, and similar equipment. This was done so that the values of C could be made as great as possible. Then there is less variation, throughout the projection of a roll, in the tension to which the film is subjected by the take-up mechanism, especially if a constant-torque device is used. Thus it is necessary to keep the ratio of flange diameter to core diameter as small as possible, and also to eliminate as many small cores as possible. For the cores, rather widely separated limits (not intended to be manufacturing tolerances) are given in order to permit the use of current reels that are known to give satisfactory results.

74th Convention

The Society's 74th Convention was just one month away as this issue of the *Journal* went to press; and it is therefore a very real pleasure to report that the Papers Program for this five-day affair that begins on Monday, October 5th, did not suffer seriously from the unseasonable summer. Skip Athey, Program Chairman, made the grade. He just beat our publication deadline with an optimistic report on the success of papers procurement efforts. The titles so far assembled are in goodly number and, equally important, are closely tied to the more notable technical developments of recent months.

Skip assures all readers that the following list of topics is firm and you will see for yourself that this schedule of events is as meaty and well balanced as any. Those who have handled similar program assignments in the past, however, will agree with Skip and his hard working assistants — Bill Rivers, Joe Aiken, George Colburn, Gerry Graham, Charles Jantzen, Ralph Lovell, Glenn Matthews, Walt Tesch and John Waddell — that credit for the resulting program is hardly recompense for effort expended.

Stereophonic sound reproduction and the projection of wide-screen pictures will be lead-off topics for the opening technical sessions on Monday, October 5th. The afternoon will be devoted to "basic principles," and the following morning, Tuesday, October 6th, there will be a group of papers on new sound and projection equipment. In their commercial applications these processes represent the latest thing in motion pictures, so attendance at these sessions should be large. From present predictions it will include heavy representation from among American and foreign theater owners. Monday evening will be reserved for the presentation of awards.

This convention will have a session on high-speed photography, now set for Tuesday morning, to run concurrently with the session on new sound and projection equipment. The Tuesday afternoon session will be devoted to motion-picture laboratory equipment and practices, and the evening session will include two groups of companion papers; one, on production of foreign language versions of American motion pictures, and the other on the related technicalities of magnetic striping. This session will be held at the Signal Corps Pictorial Center.

To maintain a custom of long-standing there will be two paper sessions on Wednesday, October 7th, followed by a cocktail party and banquet. The subject of the morning session on Wednesday will be television, with papers having mostly to do with films for television broadcasting. In the afternoon papers and discussion will center around theater television. The cocktail party and banquet will be "informal" which somewhat illogically means "formal." In other words, if you have a dinner jacket, wear it; if you don't — well, do as you please, but by all means be comfortable and have a good time.

Thursday morning, October 8th will be "open" so breakfast may be had at lunch time. Thereby we will observe once again a tradition of old, long hallowed in the hearts of Wednesday revelers, but for several seasons now sorely breached out of deference to matters technical.

In the afternoon a general interest session will be held and on Thursday evening there will be an enlightening symposium on principles of 3-D.

The session on Friday morning, October 9th, will be devoted to the subject of new wide-screen techniques. Following the general session on Friday afternoon, Herbert Barnett will call for adjournment of the 74th Convention.

All convention paper titles and authors will be listed in the Advance Program that is scheduled for early first-class mailing to all members within and without the United States. A few items of particular interest taken from that list are these:

"A 35mm Stereo Cine Camera" by Chester E. Beachell of National Film Board of Canada

"Ferrite Core Heads for Magnetic Recording" by R. J. Youngquist and W. W. Wetzel of Minnesota Mining & Mfg. Co.

"Sensitometry of the Color Internegative Process" by C. R. Anderson, C. E. Osborne, F. A. Richey and W. L. Swift of Eastman Kodak Co.
"Stereoscopic Perceptions of Size, Shape, Distance and Direction" by D. L. MacAdam of Eastman Kodak Co.
"An Auxiliary Multitrack Magnetic Sound Reproducer" by C. C. Davis and H. A. Manley of Westrex Corp.
"A Film-Pulled Theater-Type Magnetic Sound Reproducer for Use With Multitrack Films" by J. D. Phyfe and C. E. Hittle of Radio Corporation of America
"A New Vidicon Tube for Film Pickup" by R. G. Newhauser of Radio Corporation of America

There is more to a convention than papers for which the chain of command includes Norwood Simmons, Editorial Vice-President, and Bill Rivers, Chairman of the Papers Committee. Jack Servies, Convention Vice-President is top manager of the many other convention matters including luncheon, banquet and the so-essential local arrangements. His work is always well delegated and for 74th Convention these are his assistants:

Local Arrangements
Chairman — W. H. Offenhauser, Jr.
Vice-Chairman — R. C. Holslag
Vice-Chairman — S. L. Silverman

Registration — J. C. Naughton
Hospitality — Marie Douglass
Projection — Charles Muller
Public Address — George Costello and Dominick Lopez
Hotel & Transportation — L. E. Jones
Luncheon & Banquet — Emerson Yorke, J. B. McCullough and J. G. Stott
Membership — A. R. Gallo
Motion Pictures — V. J. Gilcher
Publicity — Harold Desfor and Leonard Bidwell

Current Literature

The Editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D.C., or from the New York Public Library, New York, N. Y., at prevailing rates.

American Cinematographer
vol. 34, July 1953
Single-film, Single-projector 3-D (p. 319) *N. Cohen*
3-D Television (p. 320)
Vistarama — Wide-Screen System for 16mm Movies (p. 326) *H. A. Lightman*

Bell System Technical Journal
vol. 32, July 1953
Television Terminals (p. 915) *J. W. Rieke and R. S. Graham*

Electronics
vol. 26, Aug. 1953
Standards Converter for International TV (p. 144) *A. V. Lord*
Design of Export Television Receivers (p. 174) *G. D. Hulst*

Focus
vol. 38, no. 13, June 27, 1953
De Nieuwe Philips Televisie-camera (p. 267)

Ideal Kinema (Supplement to Kinematograph Weekly)
vol. 19, July 9, 1953
Carbons to Light the Wide Screen (p. 5) *R. H. Cricks*
The Equipment Behind CinemaScope (p. 9)
The Mathematics of Wide Screen (p. 17)

Proceedings of the I.R.E.
vol. 41, July 1953
Colorimetry in Color Television (p. 838) *F. J. Bingley*
The PDF Chromatron — A Single or Multi-Gun Tri-Color Cathode-Ray Tube (p. 851) *R. Dressler*
vol. 41, Aug. 1953
A Subjective Study of Color Synchronization Performance (p. 979) *M. I. Burgett, Jr.*

International Photographer
vol. 25, Aug. 1953
Editing 3-D (p. 5) *R. Fehr*
Processing Color Film, Pt. 2 (p. 22) *G. Ashton*
Graphic Representation of Various 3-D and Wide Screen Processes (p. 23)

International Projectionist

vol. 28, July 1953

Round-Up of the Wide-Screen Process (p. 5)

Visibility Factors in Projection, Pt. 3 — Color and Nature of Projection Light (p. 11) *R. A. Mitchell*

Projector Carbons for New Motion Picture Systems (p. 14) *F. P. Holloway, R. M. Bushong and W. W. Lozier*

Kino-Technik

vol. 7, July 1953

Der heutige Stand der Filmwissenschaft in Deutschland (p. 184) *E. Feldmann*

Raumfilm — mit Farbe Wirklichkeitsnah (p. 186) *H. N. O'Leary*

Moglichkeiten und Grenze der Farbkorrektur (p. 188) *A. Kocks*

Storungen bei der Vorfuhrung von Tonfilmen (p. 193) *H. Tummel*

Die Moglichkeiten zur Vertonung von Amateurfilmen (p. 194) *F. Frese*

Cameflex-Fernsehkamera Modell "T" 16mm (p. 198)

Motion Picture Herald (Better Theatres Section)

vol. 191, July 4, 1953

Crisis in Sound, 1953 (p. 11)

Precision Requirements of 3-D: Shutter Synchronization, Interlocking and Alignment (p. 15) *G. Gagliardi*

vol. 191, Aug. 1, 1953

Projection Factors of Wide-Screen Installation (p. 8) *G. Gagliardi*

New Carbons for the New Projection System (p. 31) *F. P. Holloway, R. M. Bushong and W. W. Lozier*

Radio & Television News

vol. 50, no. 2, Aug. 1953

Film for TV (p. 35) *H. J. Seitz*

Troubleshooting TV High-voltage Supplies (p. 48) *M. H. Lowe*

Know Your 1953 Emerson TV Receivers (p. 52) *B. Kutny*

R & TV News (Radio-Electronic Eng. Sec.)

vol. 50, no. 2, Aug. 1953

Pressure Testing of TV Tubes (p. 8) *G. D. Ostrander*

RCA Review

vol. 14, June 1953

Optimum Utilization of the Radio Frequency Channel for Color Television (p. 133) *R. D. Kell and A. C. Schroeder*

Principles and Development of Color Television Systems (p. 144) *G. H. Brown and D. G. C. Luck*

Color Television Signal Receiver Demodulators (p. 205) *D. H. Pritchard and R. N. Rhodes*

Colorimetric Analysis of RCA Color Television System (p. 227) *D. W. Epstein*

TV & Radio Engineering

vol. 23, no. 3, June-July 1953

Microwave Units for TV Services (p. 14) *S. Topal and W. T. Beers*

16-mm Projector for Television (p. 17)

Color TV Experimental Equipment (p. 19)

Low Cost TV Camera (p. 28)

Book Reviews

Photoelectric Tubes

By A. Sommer. Published (late 1952) by John Wiley & Sons, 440 Fourth Ave., New York 16. 118 pp. 27 diagrams. 4 × 6½ in. $1.90.

It would seem improbable that this little volume could treat the emissive type of photocell from the basis for the photoelectric effect in Einstein's and Fermi's theories, through physical aspects, chemical nature of complex cathodes, manufacturing techniques, spectral response and engineering application. Yet it does, and clearly.

The chapter headings give further clues as to what is to be found in the book: I, Historical Introduction; II, Theories of Photoelectric Emission; III, Photoelectric Cathodes; IV, Matching of Light Sources and Photocathodes; V, Vacuum Photocells; VI, Gasfilled Photocells; VII, Multiplier Photocells; and VIII, Applications of Photocells.

Material is included on the direct applications to sound motion pictures and television, which serves to relate all other material to the chief interest of the readers of this *Journal*.

Dr. Sommer is of the EMI Research Laboratories in England, but it appears that the British electrons behave exactly the same as do the American ones. Furthermore, American tubes are discussed. A convenient table of photocathode types for a dozen tubes and a bibliography of 69 entries to the scientific and engineering literature of both the United States and Europe are included.—*Harry R. Lubcke*, Registered Patent Agent, 2443 Creston Way, Hollywood 28, Calif.

Photography, Its Materials and Processes, 5th ed.

By C. B. Neblette and 14 collaborators. Published (1952) by C. Van Nostrand. 250 Fourth Ave., New York 3. vii + 490 pp. + 10 pp. index. 350 illus. 7 × 9½ in. $10.00.

Ed. Note: We have been unable to get a review long ago promised for the *Journal*. Rather than let this book go unnoticed, we have obtained permission to reprint the following review by Dr. O. W. Richards, American Optical Co., Stamford, Conn., from the *Journal of the Biological Photographic Assn., 20:* 121, Aug. 1952.

For twenty-five years this has been a standard book for photographers. Now it is encyclopedic and much of it has been written by experts including our Lloyd Varden. This volume of 33 chapters is primarily on materials and their use, shows the increasing technical progress in the field. Gone are chapters on enlarging and lantern slide making. Instead the emphasis is now on color. With the exception of a few chapters (including Varden's) the rest of the book is made from reference material up to about 1945 or 1947, so that some of it is already out of date. The section on electronic flash, for example, does not mention the new smaller tubes and the convenient voltage doubler circuits. For a student textbook, that it still states that it is, a chapter on the essentials of a good picture would add to the usefulness of the book. While it will probably be rather difficult reading for the beginner, the advanced photographer will find most of his questions answered and no department should be without this remarkably complete reference book.—*O.W.R.*

Television Scripts for Staging and Study

By Rudy Bretz and Edward Stasheff. Published (1953) by A. A. Wyn, 23 W. 47 St., New York 36. 328 pp. + 4 pp. index. Numerous illus. $4.95.

An earlier book, *The Television Program* by the same authors, was reviewed for this *Journal* with the conclusion that it did all that a book could do for those learning television production. The earlier reviewer emphasized the values of actual experience and observation. These authors are aware of those values for they have extensive experience teaching where complete equipment was a part of the school. They are both still teaching, between or along with other stints. And while their first book goes on being adopted as the text in additional dozens of schools and universities, this book comes as an additional tool for the teacher and student director or producer.

Considering that, in this *Journal's* modest fan mail, the commonest specific reference has been to articles by Author Bretz, we need not here attempt to assess in any detail the parts of this book. Introductory to the second and third parts of the book, which are "The Simpler Formats" and "Full-Length Scripts," is the friend-of-the-engineer part, "Creative Camera Techniques" which includes chapters on pictorial composition (control over subject) and shots in sequence (cutting techniques). We suggest that student and learning directors who become aware of what can and cannot be done with their studio facilities are important contributors to a well-engineered picture on the air.—*V.A.*

Technical Reporting

By Joseph N. Ulman, Jr. Published (1952) by Henry Holt, 383 Madison Ave., New York 17. i-xiv + 284 pp. + 5 pp. index. $4.75.

This is a good book for the many who need such a book. We are in favor of all such books, just as all busy editors are against the crimes which writers attempt against the general welfare of the readers.

Technical Reporting is shorter than many books telling engineers how to write because the author has followed his own advice: "You owe it to your reader to make your meaning immediately clear with a minimum of study on his part."

The author does not have the futile ambition to make grammarians out of technical men. He has prepared a text which is worthy of study and recurrent browsing and is useful in a modest way as a reference. He lists other books which

serve standard reference purposes. This is not an officious apologia for a volume of fine points. It is an efficient presentation of common-sense bases for effective technical writing. The Table of Contents is a pleasure to read and use for it is fully but not ponderously supported by the text.—*V.A.*

Television Factbook, No. 17 July 15, 1953

Published (July 15, 1953) by Radio News Bureau, Wyatt Bldg., Washington 5, D.C. 356 pp. incl. folding wall map in color. $8\frac{1}{2} \times 11$ in. $3.00.

The new 1953 midyear edition of this vast compendium of facts about the television world has a number of new departments, including sets-in-use by states and counties (both NBC Research's TV-&-radio count and CBS's TV count); the J. Walter Thompson Co. study of households and TV sets in "First 312 Markets of the U.S."; directory of TV stations in foreign countries; tables showing annual volume of advertising in U.S. by media, 1946–52; tabulation of financial data on leading TV-radio manufacturers; and first detailed listings of tuner, converter and receiving antenna manufacturers.

The *Factbook* provides personnel listings, facilities and ownership data and rate card digests of all TV networks (including the new Canadian), and of the 227 U.S. stations now operating or due to be in operation by August 1, and tabulations of new-station applications pending and outstanding construction permits.

Among other features are directories of program sources, FCC personnel, attorneys, engineers, consultants, trade associations, unions, publications, etc.; listings of community antenna systems, theaters equipped for TV, and directories of manufacturers of receivers, tubes, transmitters, studio equipment, etc.; channel allocation tables; FCC priority lists; network TV-radio billings, 1949–53; and FCC reports on revenues, expenses and earnings of TV networks and stations, 1946–52.

American Cinematographer Hand Book and Reference Guide

By Jackson J. Rose. Published (1953) by American Cinematographer Hand Book, 458 So. Doheny Dr., Beverly Hills, Calif. 8th ed., 328 pp., incl. advts. $4 \times 6\frac{1}{2}$ in. Flexible binding. Price $5.00.

The Eighth Edition of this standard reference guide has the charts, tabulations, formulas and indexes with which users of previous editions will be familiar. This edition has been announced as also covering these new features: Cinerama, television photography, zoom lenses, latensification, underwater photography, background projection, T-stops, Ansco Color Negative-Positive Process, Eastman Color Negative and Print Film, Du Pont Color Release Positive Film and many new charts and tables.

Workers in motion-picture and still photography and in television will find this still a very useful reference as last described when the seventh edition was reviewed in September 1950 in the *Journal*. — *V.A.*

"Research Film"

The Research Film Committee of the International Scientific Film Association announces a new bulletin, *Research Film*, designed as a vehicle for the international exchange of information in the field of its title. The tri-lingual publication is under the editorship of Dr. G. Wolf of Gottingen and Jean Dragesco of Paris. Notices appear in French, German and English; articles are published in their original language. Reports on American work are sought. Further information can be obtained from the chairman of the Research Film Committee, Dr. G. Wolf, Institut fur Film und Bild — Abt. Hochschule und Forschung, Bunsenstrasse 10, Gottingen, Germany.

SMPTE Officers and Committees: The roster of Society Officers and the Committee Chairmen and Members were published in the April *Journal*.

New Members

The following members have been added to the Society's rolls since those last published. The designations of grades are the same as those used in the 1952 MEMBERSHIP DIRECTORY.

Honorary (H) Fellow (F) Active (M) Associate (A) Student (S)

Austin, Otto, Motion-Picture Producer, Austin Productions, Inc., 232½ North Main St., Lima, Ohio. (A)

Ayling, Russell J., Electrical Engineer, Strong Electric Corp., 87 City Park Ave., Toledo, Ohio. (M)

Bass, Vincent F., Cinematographer, Photographer. **Mail:** 564 Rutland Ave., San Jose 28, Calif. (A)

Becker, Sherwin H., Editor, Douglas Productions. **Mail:** 5214½ South Drexel Blvd., Chicago 15, Ill. (A)

Berliner, Oliver, Audio-Video Consulting, Oberline, Ltd., 6411 Hollywood Blvd., Hollywood 28, Calif. (A)

Bogardus, John O., Motion-Picture Projectionist, W. S. Butterfield Theatres, Inc. **Mail:** 344 Coldbrook, N.E., Grand Rapids 5, Mich. (M)

Carlson, George, Television Supervisor, KSTP-TV, Inc., St. Paul, Minn. (M)

Constable, James M., Producer-Director, Wilding Picture Productions, Inc., 1345 Argyle St., Chicago, Ill. (M)

Di Lonardo, Hugh, Motion-Picture and Television Films Instructor, Television Workshop. **Mail:** 75 W. 97 St., New York, N.Y. (A)

Druz, Walter S., Research Engineer, Zenith Radio Corp. **Mail:** 228 South Center St., Bensenville, Ill. (M)

Dyer, Robert W., Studio Manager, Motion Picture Advertising Service Co., Inc., 1032 Carondelet St., New Orleans, La. (M)

Gaines, Albert, Motion-Picture Laboratory Technician, DeLuxe Laboratories. **Mail:** c/o Greenwald, 3210 Perry Ave., Bronx, N.Y. (A)

Grodin, Burton, President, University Camera Exchange. **Mail:** 3678 Crest Rd., Wantagh, Long Island, N.Y. (M)

Herrick, Kenneth P., Field Engineer, Radio Corporation of America. **Mail:** 2516 Fulton St., Toledo, Ohio. (A)

Hughes, Tom F., Motion-Picture Production Supervisor, American Airlines, Inc. **Mail:** 44 Shadyside Ave., Port Washington, N.Y. (A)

Imus, Henry O., Color Camera Technician, Technicolor Motion Picture Corp. **Mail:** 3180 Vista Del Mar, Glendale 8, Calif. (A)

Jarrett, A. W., Motion-Picture Cameraman, KOB-TV. **Mail:** 1934 Meadow View Rd., Albuquerque 1, N.M. (A)

Jensen, Peter Axel, Research Trainee, Technicolor Motion Picture Corp., Box 16-547, Hollywood 38, Calif. (A)

Keilhack, Francis W., Representative and Technical Adviser, Drive-In Theatre Manufacturing Co., 505 W. Ninth St., Kansas City, Mo. (M)

Koerner, Allan M., Eastman Kodak Co., Kodak Park, Bldg. 65, Rochester, N.Y. (A)

Krtous, George F., Engineer, De Vry Corp. **Mail:** 2547 South Harding Ave., Chicago 23, Ill. (M)

Laby, Lawrence M., Production Manager, Natural Vision Theatre Equipment Corp. **Mail:** 5461 Tampa Ave., Tarzana, Calif. (A)

Langendorf, Matthew P., Engineer, Ampro Corp. **Mail:** 3512 West Lemoyne St., Chicago 51, Ill. (M)

Lester, F. C., Broadcast Engineer, Mid-Continent Broadcasting Co., KOWH. **Mail:** 3514 N. 61 St., Omaha, Nebr. (A)

Lovell, Herman J., Chief Engineer, WKY Radiophone Co., 500 East Britton Rd., Oklahoma City, Okla. (M)

Lucas, James W., Aircraft and Mechanical Engineer, The Stephen-Douglas Co. **Mail:** 311 South Amalfi Dr., Santa Monica, Calif. (A)

Mavrides, William, Film Editor and Film Librarian, WAKR-TV, First National Tower, Akron, Ohio. (A)

Merrifield, Robert C., Television Set Lighting Technician. KLAC-TV. **Mail:** 220 South Hoover St., Los Angeles 4, Calif. (A)

Mirarchi, Michael R., Photographic Technician, Signal Corps Engineering Laboratories. **Mail:** 141 Atlantic Ave., Long Branch, N.J. (A)

Navarro, Jose C, Cinematographer, Television Technical Director, DZAQ-TV. **Mail:** 1230 Oroguieta, Sta. Cruz, Manila, Philippines. (A)

Newman, Robert P., Film Executive, Telepix Corp., 1515 North Western Ave., Hollywood, Calif. (M)

Reid, Seerley, Chief, Visual Education Service, U.S. Office of Education, Washington 25, D.C. (A)

Reynolds, Ernest M., Motion-Picture and Slide-Film Producer. **Mail:** 165 E. 191 St., Cleveland 19, Ohio. (M)

Richartz, Paul, Design Engineer, Bell & Howell Co. **Mail:** 87 Orchid Rd., Levittown, Long Island, N.Y. (M)

Richter, A. A., Service Engineer, Army and Air Force Motion Picture Service. **Mail:** 4927 Imlay Ave., Culver City, Calif. (**A**)

Rolph, Donald B., Motion-Picture Sound Recording. **Mail:** 15450 Pepper La., Los Gatos, Calif. (**A**)

Schley, Norman E., Cameraman, Director, Picturelogue, Inc., 204 Wisconsin Ave., Waukesha, Wis. (**M**)

Sherburne, Edward G., Jr., Navy Special Devices Center. **Mail:** 10 Clent Rd., Great Neck, N.Y. (**M**)

Stadig, Sidney V., TV Technical Supervisor, Westinghouse Radio Stations, Inc. **Mail:** 86 Spring St., Lexington, Mass. (**M**)

Walls, Fred M., Sound Engineer. **Mail:** 827 Wayne, Topeka, Kan. (**M**)

Washick, Walter J., Design Draftsman, Technicolor Motion Picture Corp. **Mail:** 1931 Lietz Ave., Burbank, Calif. (**A**)

Wilson, Jimmy, Producer and Photographer, Jimmy Wilson Studios, 724 S. 29 St., Birmingham, Ala. (**M**)

Winter, A. Roane, Assistant Sound Engineer, Missions Visualized, Inc. **Mail:** 1034 East Walnut Ave., Burbank, Calif. (**A**)

Wohler, Johann F., Optical Engineer, A. G. Optical Co., 5574 Northwest Highway, Chicago, Ill. (**M**)

CHANGES IN GRADE

Clarke, Anthony, (**S**) to (**A**)

Fullerton, Richard D., (**A**) to (**M**)

Tinker, Clarence J., (**A**) to (**M**)

Chemical Corner

Edited by Irving M. Ewig for the Society's Laboratory Practice Committee. Suggestions should be sent to Society headquarters marked for the attention of Mr. Ewig. Neither the Society nor the Editor assumes any responsibility for the validity of the statements contained in this column. They are intended as suggestions for further investigation by interested persons.

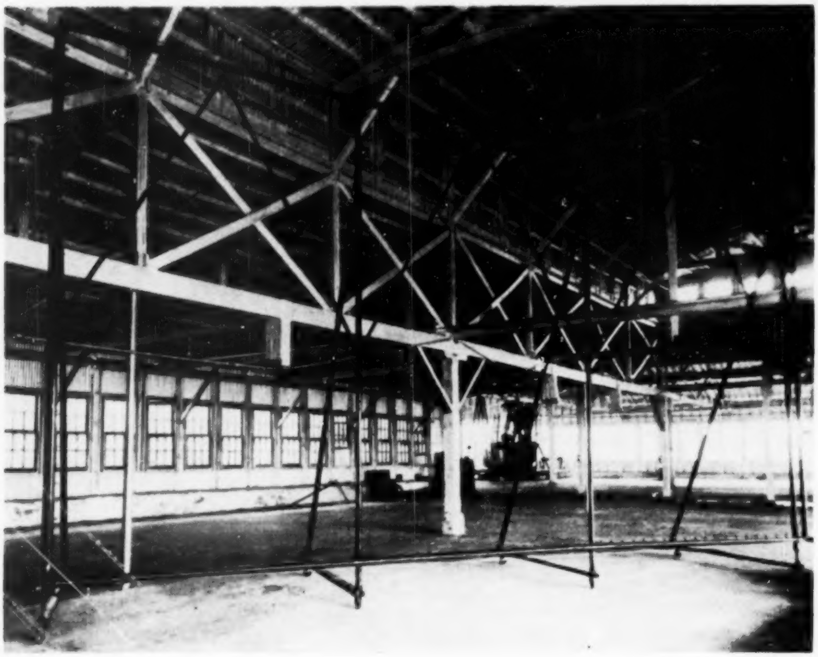
Saving Shipping Costs The laboratory plagued by high chemical shipping costs ought to consider the substitution of sodium thiosulfate-anhydrous for the crystalline hypo which contains 35% water. The ultimate cost of hypo can be determined on the basis that 65 lb of the anhydrous variety is equal to 100 lb of the common crystalline type. The use of anhydrous sodium carbonate (soda ash) can be substituted effectively for sodium carbonate-monohydrate on 85:100 lb basis. Also soda ash is stocked at various shipping fronts throughout the country.

A Universal Adhesive A new adhesive that may prove of interest to the motion-picture and television industries can be used to adhere felt, cork, sponge, solid rubber, etc., to a variety of surfaces. The manufacturer, The Rubber Latex Co. of America, 110 Delawanna Ave., Clifton, N.J., claims that their adhesive is the most universal one developed in recent years. The product, designated Rula 181-3, can be applied to rolls or sheets like paint and allowed to dry. Parts cut from the coated rolls or sheets can be shipped or laid aside, and upon being remoistened with a petroleum-type solvent or cleaning fluid, may be pressed into place on any surface such as steel, wood, paint, plaster, paper, glass, ceramics, etc., and become permanently adhered after an extremely short drying period. The adhesive may also be used in the conventional manner by applying and using while still wet.

This May Be a Good Film Cement A cement which has exceptionally good adhesive properties for cellulose acetate is called C D Cement #150. It is colorless, fast-acting and produces an unusually strong bond. This product may have possibilities as a good film cement and anyone interested should consult the manufacturer, The Chemical Development Corp., Danvers, Mass.

New Products

Further information about these items can be obtained direct from the addresses given. As in the case of technical papers, the Society is not responsible for manufacturers' statements, and publication of these items does not constitute endorsement of the products.



The Bowline Screen Frame is made of steel tubing, reportedly can be installed in less than an hour without special skills, and weighs about a pound for each square foot of screen surface — for a 20 × 30 ft screen, about 600 lb. The frame's adjustability is described: height, adjustable so that any aspect ratio can be obtained; tilt, degree of tilt easily set; curve, with radius laid off on the floor, the frame is set directly over the position line and formed. Both the tilt and the curvature can be varied or the frame can be adjusted to provide a flat screen. It is manufactured by H. R. Mitchell and Co., Hartsell, Ala.

SMPTE Lapel Pins

The Society has available for mailing its gold and blue enamel lapel pin, with a screw back. The pin is a ½-in. reproduction of the Society symbol — the film, sprocket and television tube — which appears on the *Journal* cover. The price of the pin is $4.00, including Federal Tax; in New York City, add 3% sales tax.

The Spectra Color Densitometer, manufactured by Photo Research Corp., 127 West Alameda Ave., Burbank, Calif., measures black-and-white (both print and visual), color and sound track by infrared phototube. The left head is used for black-and-white and color; the right head for sound track. A special interference filter can be used to limit the sensitivity to a narrow band at the peak region of infrared sensitivity. Separate zero adjustments for the blue, green and red color positions permit readings to be taken of a given patch without moving the film. The left head is always ready for black-and-white and color readings and the right head for sound-track readings. Change from one to the other is made by a switch. Both heads have special illuminated disks surrounding the apertures to facilitate finding desired areas.

Employment Service

These notices are published for the service of the membership and the field. They are inserted for three months, and there is no charge to the member.

Positions Wanted

Experienced motion-picture production man desires connection with film company as producer-director or production manager. During past 12 yrs. experience includes directing, photographing, editing, recording and processing half-million feet finished film, including educational films, industrials, TV spots, package shows for TV and experimental films. University graduate, married, twenty-nine years old; good references. Locate anywhere continental U.S. Write Victor Duncan, 8715 Rexford Drive, Dallas 9, Tex.

Film Production/Use: Experienced in writing, directing, editing, photography; currently in charge of public relations, sales and training film production for industrial organization. Solid film and TV background, capable administrator, creative ability, degree. References and résumé upon request. Write FPF, Room 704, 342 Madison Ave., New York 17, N.Y.

Position Available

Wanted: Optical Engineer for permanent position with manufacturer of a wide variety of optics including camera objectives, projector, microscope and telescope optics, etc. Position involves design, development and production engineering. Send résumé of training and experience to Simpson Optical Mfg. Co., 3200 W. Carroll Ave., Chicago 24, Ill.

Department of Defense Symposium on Magnetic Recording

A full and worth-while program has been arranged to be held on October 12 and 13 in the Department of Interior Auditorium, Washington, D.C. The organizers plan to avoid a rehash of basic theory and intend the symposium to be a meeting ground where different branches of the magnetic recording industry may exchange views for their general benefit, as well as for the benefit of the Department of Defense. Individuals from industry engaged in magnetic recording development are invited to attend. There is no fee for registration.

E. W. D'Arcy will give a paper on "Calibrated Recordings and Measurement Techniques," reviewing the Society's position as reflected by progress on the subcommittee which he heads; and John G. Frayne is scheduled to present a paper on "Components and Mechanical Considerations."

SMPTE representative for the Armed Forces Symposium has been Joseph E. Aiken, Naval Photographic Center, Anacostia, D.C.

Meetings

The Royal Photographic Society's Centenary, International Conference on the Science and Applications of Photography, Sept. 19–25, London, England

National Electronics Conference, 9th Annual Conference, Sept. 28–30, Hotel Sherman, Chicago

74th Semiannual Convention of the SMPTE, Oct. 5–9, Hotel Statler, New York

Audio Engineering Society, Fifth Annual Convention, Oct. 14–17, Hotel New Yorker, New York, N.Y.

Society of Motion Picture and Television Engineers, Central Section Meeting, Oct. 15 (tentative), Chicago, Ill.

Theatre Equipment and Supply Manufacturers' Association Convention (in conjunction with Theatre Equipment Dealers' Association and Theatre Owners of America), Oct. 31–Nov. 4, Conrad Hilton Hotel, Chicago, Ill.

Theatre Owners of America, Annual Convention and Trade Show, Nov. 1–5, Chicago, Ill.

National Electrical Manufacturers Association, Nov. 9–12, Haddon Hall Hotel, Atlantic City, N.J.

Society of Motion Picture and Television Engineers, Central Section Meeting, Nov. 12 (tentative), Chicago Ill.

The American Society of Mechanical Engineers, Annual Meeting, Nov. 29–Dec. 4, Statler Hotel, N.Y.

Society of Motion Picture and Television Engineers, Central Section Meeting, Dec. 10 (tentative), Chicago, Ill.

American Institute of Electrical Engineers, Winter General Meeting, Jan. 18–22, 1954, New York

National Electrical Manufacturers Assn., Mar. 8–11, 1954, Edgewater Beach Hotel, Chicago, Ill.

Radio Engineering Show and I.R.E. National Convention, Mar. 22–25, 1954, Hotel Waldorf Astoria, New York

Optical Society of America, Mar. 25–27, 1954, New York

75th Semiannual Convention of the SMPTE, May 3–7, 1954, Hotel Statler, Washington

Acoustical Society of America, June 22–26, 1954, Hotel Statler, New York

76th Semiannual Convention of the SMPTE, Oct. 18–22, 1954 (next year), Ambassador Hotel, Los Angeles

77th Semiannual Convention of the SMPTE, Apr. 17–22, 1955, Drake Hotel, Chicago

78th Semiannual Convention of the SMPTE, Oct. 3–7, 1955, Lake Placid Club, Essex County, N.Y.

Society of Motion Picture and Television Engineers

40 West 40th Street, New York 18, N. Y., Tel. LOngacre 5-0172
Boyce Nemec, *Executive Secretary*

Sustaining Members

OF THE

SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

Alexander Film Co.
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Bell & Howell Company
Bijou Amusement Company
Burnett-Timken Research Laboratory
Byron, Inc.
The Calvin Company
Cinecolor Corporation
Cineffects, Inc.
Cinéma-Tirage L. Maurice
Geo. W. Colburn Laboratory, Inc.
Consolidated Film Industries
DeLuxe Laboratories, Inc.
De Vry Corporation
Du-Art Film Laboratories, Inc.
E. I. du Pont de Nemours & Co., Inc.
Eastman Kodak Company
Max Factor, Inc.
Federal Manufacturing and Engineering Corp.
Fordel Film Laboratories
General Electric Company
General Precision Equipment Corp.
- Ampro Corporation
- Askania Regulator Company
- General Precision Laboratory, Incorporated
- The Hertner Electric Company
- International Projector Corporation
- J. E. McAuley Mfg. Co.
- National Theatre Supply
- The Strong Electric Company

W. J. German, Inc.
Guffanti Film Laboratories, Inc.
Hunt's Theatres
Hurley Screen Company, Inc.
The Jam Handy Organization, Inc.
Kollmorgen Optical Corporation
Lorraine Carbons
March of Time
J. A. Maurer, Inc.
Mecca Film Laboratories, Inc.
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Mole-Richardson Co.
Motiograph, Inc.
Motion Picture Association of America, Inc.
- Allied Artists Productions, Inc.
- Columbia Pictures Corporation
- Loew's Inc.
- Paramount Pictures Corporation
- Republic Pictures Corp.
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JOURNAL OF THE
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TELEVISION
ENGINEERS

DEVELOPMENTS IN STEREOPHONY

From SMPTE 73d Convention

From 1934 Bell Symposium

THIS ISSUE IN TWO PARTS—PART II

Part I, September 1953 Journal

Part II, Developments in Stereophony

SEPTEMBER 1953

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PART II OF THE SEPTEMBER 1953 JOURNAL

Developments in Stereophony

The first six papers in this group were presented at the Society's Convention at Los Angeles, April 27 – May 1, 1953. The last three papers are reprinted from a symposium on auditory perspective presented at the winter convention of the American Institute of Electrical Engineers, January 1934, and published in *Electrical Engineering* for January 1934 and in the *Bell System Technical Journal* for April 1934.

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Foreword
Developments in Stereophony

By WILLIAM B. SNOW

Reproduction of sound giving the illusion of auditory perspective has been shown periodically for many years. Beginning in 1931 the Bell Telephone Laboratories conducted an extensive study of the subject when truly high fidelity sound reproducing equipment became available. The results of these studies were reported at the January 1934 convention of the American Institute of Electrical Engineers, and were published in a series of six papers in *Electrical Engineering* of January 1934.

This type of reproduction is now known as "stereophonic." Industry was not ready for stereophony in 1934, but recently the subject has become of vital importance to all who must record or reproduce sound. In the intervening years relatively little work on fundamentals has been reported and three of the original articles contain data of real value to present-day workers in the field. Since these papers are no longer readily available in sufficient quantity, the Society is republishing them in this issue of the *Journal*.

The application of stereophonic principles, together with other advanced techniques, to film recording was described in a 1941 Symposium sponsored by the SMPE and Acoustical Society of America. A group of papers on this subject was published by the Society in the October 1941 *Journal*. These papers also contain much information applicable to today's problems, and are recommended for study in connection with the older papers republished here.

Space limitations preclude a complete discussion of the advances made since 1934, but it is believed the comments below will add value to study of the papers.

The paper "Basic Requirements," republished in this Part of the *Journal*, and that on "General Theory" in the 1941 Symposium, both by Dr. Harvey Fletcher, discuss the same fundamental problem from somewhat different points of view. They supplement each other and it will be found profitable to study them together.

"Basic Requirements" and the paper on "Physical Factors," also republished now, point out that an ideal reproducing system would employ an infinite number of microphones and loudspeakers, which would duplicate the original sound, and would be listened to binaurally in the ordinary way. It must be continually borne in mind that a stereophonic system with a practical number of channels creates its illusion in a different way; each ear receives a sound image from each loudspeaker and these are put together or fused to yield a single composite impression. This is implicit in the computations of the article "Physical Factors," but has not been generally understood. The same clues are used in

both types of listening — intensity, quality, arrival time — but not in the same way.

The article points out that the computations failed to explain some of the observed effects. It has since been found that the discrepancies were largely caused by arrival time differences. The apparent direction of the sound tends toward the loudspeaker from which the reproduction of a given source arrives first. Thus, approaching a microphone increases the intensity and advances the arrival time, both effects causing the sound image to shift toward that channel. When an observer moves toward the side of the listening room he approaches the corresponding loudspeaker, again advancing the arrival time and increasing the intensity on that channel. Only the intensity effect was included in the calculations.

The paper on "Loudspeakers and Microphones" is concerned with fundamental theory employed in the design of moving-coil and horn-type instruments. It contains a discussion of the philosophy of establishing performance requirements, in addition to the mathematical methods needed for design. The intervening years have emphasized the value of these methods, but have also shown that the actual adaptation of loudspeaker and microphone characteristics to most desirable overall system response is a matter of judgment in particular cases, as implied by this paper.

Stereophonic Recording and Reproducing System

By HARVEY FLETCHER

The historical background and design requirements of three-dimensional sound systems are discussed. Particular attention is given to the requirements for reproducing low-frequency sounds.

Stereophonic Transmission System

In 1933, engineers of the Bell System demonstrated a new transmission apparatus which permitted unusually faithful reproduction, at distant points, of tonal effects produced on the local concert or opera stage. In the demonstration, a performance by the Philadelphia Symphony Orchestra was picked up in the Academy of Music in Philadelphia and electrically transmitted to Constitution Hall, Washington, D.C., where it was reproduced from the stage, in auditory perspective, to a distinguished audience.

The new apparatus, later referred to as the stereophonic transmission system, was described in a series of papers on auditory perspective presented before the A.I.E.E. in 1934.* It consisted essentially of three complete channels working together, each comprising a microphone, a high-gain amplifier, a predistorting and corrective network, a variable distorting network and attenuator, a power amplifier and a loudspeaker.

Not only did the system make possible an apparently distortion-free facsimile of the original music; it also included what was known as an enhancement feature. While listening to the reproduced music the director of the orchestra was able by means of controls on attenuators to raise and lower at will the intensity level of each channel. By means of appropriate switches, he could increase or decrease the level of the bass, or make the music less or more shrill by throwing in or out networks having a sloping frequency-loss characteristic. These networks were designed to produce changes in the frequency-response characteristics of the system. There were also auxiliary control circuits used for giving signals to the orchestra, governing the tempo, and giving instructions to the leader of the orchestra.

Presented on April 27, 1953, at the Society's Convention at Los Angeles by Harvey Fletcher, Department of Research, Brigham Young University, Provo, Utah.
(This paper was received on July 1, 1953.)

* A major portion of those papers is reprinted in this issue of the *Journal.*

Stereophonic-Recording-Reproducing System or Sound-Film System

In the development of the stereophonic sound-film system (SSFS) nearly all the features of the stereophonic transmission system described above were retained. The loudspeakers, power amplifiers and microphones are the same and the attenuating and equalizing networks are similar. But compressors and expanders were necessary due to the limitation of signal-to-noise ratio of the film. The requirements upon which the design of both the transmission system and the recording-reproducing system are based are fundamentally the same.

It is well known that when an orchestra plays, vibrations continually changing in form and intensity are set up in the air of the hall where the recording is made. An ideal system is one which will make a record of these vibrations and at any desired later time reproduce them so as to produce at every position in the hall the same time sequences of wave motion as were produced during the recording. To accomplish this for a sound source which is spread out, such as an orchestra on a stage, requires more than one channel.

Suppose there were interposed between the orchestra and the audience a sound-transparent curtain on which were mounted small microphones for picking up the sound going through the curtain; and suppose to each microphone there is connected an ideal recording system. Records made with such an ideal system would have stored on them a complete history of the sound changes at every position on the curtain. Now if small ideal loudspeakers were placed at the positions occupied by the microphones and connected to ideal machines reproducing the records, then a sheet of sound would be reproduced having all the characteristics of the original sound. Theoretically, there should be an infinite number of such record-reproducer sets. Practically, however, only a few such channels are needed. On a large stage it was found that three channels are sufficient. A three-channel system was developed originally, not only because it gave better representation of movements on a large stage than two channels, but also because of the possibility of using the center channel for solo work while still retaining partially the stereophonic features of the orchestra on the two side channels. If one wished as much flexibility up and down as the three-channel system gives from side to side, the channels would have to be increased from three to nine. However, a three-channel system, two on the horizontal and one at the top of the stage will give directional effects up and down as well as horizontal.

If one wanted to go still farther and have sound sources located around a semicircle partly surrounding the audience, several separate channels on the horizontal level would be required, or one might have a nest of microphones directly over the stage of action. In the reproduction process, a loudspeaker must be placed at the position on the stage where each microphone was placed when the recording was made.

For the usual construction of stage and auditorium the use of three channels has been found to give a good illusion of the motion of sound sources. A sound source which moves upstage decreases in intensity and increases in its reverberation content. Both of these effects are preserved in the reproduced sound so as to produce the illusion of the sound moving right, left, forward and back.

In a three-channel system, there is still not a perfect correspondence between the actual position of the source of sound during the recording and the apparent position of the recorded sound as judged by a group of observers, but it is good enough for most entertainment purposes. With a two-channel system the correspondence is much poorer and is unsatisfactory for many purposes. In

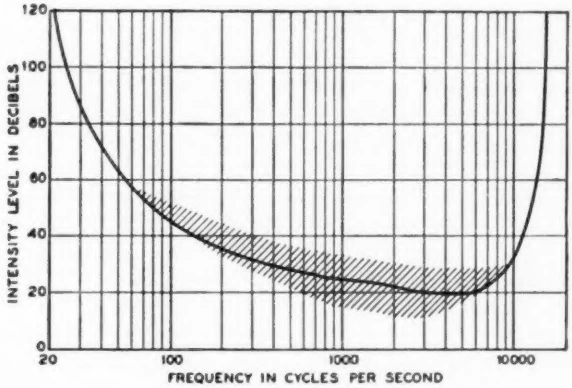

Figure 1

some of the present-day wide-vision systems, more than three channels are being used.

Stereophonic systems do not consist of two, three, or any other fixed number of channels. There must be sufficient of these to give a good illusion of an infinite number.

It is important to recognize the difference between a stereophonic system and a binaural system. The former system uses loudspeakers but requires an infinite number of channels for perfect reproduction. The latter requires only two channels for perfect reproduction but involves the use of a pair of head receivers held tightly to the ears for each listener. All listeners with such a system can be given the illusion of sitting in the best seat in the concert hall.

However, the desired illusion will be partially or completely destroyed, unless each of the channels is capable of recording and reproducing without distortion the range of frequencies and intensities which the human ear can perceive. This is, of course, a big order, but it is worth while to set down here what these ranges are.

The lowest intensity of sound that the ear can sense is determined by the audience noise. Measurements of audience noise levels in the Philadelphia Academy of Music indicate minimum levels as low as 33 db. In a quiet motion-picture theater measurements have shown the minimum to be more nearly 42 db. So for design purposes we may start with a level of about 42 db. Measurements have also indicated that the masking levels of pure tones in noises of this character and magnitude, that is, the level at which pure tones will just be audible, are those given in Fig. 1.

The shaded portion gives the expected variation due to different theaters and audiences. The curve shows the limits of hearing in both the frequency and intensity ranges.

The maximum intensity level tolerable to the ear is between 120 and 130 db and is about the same for all frequencies. Using 120 db it is seen that the range of intensity levels is between 80 and 90 db. This is a greater range than any known recording medium can accommodate. Compromises therefore must be made depending upon the kind of reproduced sound desired. If the sound of a large caliber shell exploding or of thunder claps is to be reproduced, this wide range is necessary. The method of determining the design objectives is about the same for all sounds and it will be illustrated here for a system designed to reproduce music from a large orchestra.

Experimental data on the sounds coming from such an orchestra and noise levels due to the film or tape used in the recording must be obtained. Table I shows the peak levels in critical bandwidths created at the conductor's stand during the playing of a very loud piece of music.

Table I. Peak Sound Levels in Critical Bandwidths.

Frequency (cycles/sec)	Pressure level (db)	Frequency (cycles/sec)	Pressure level (db)
50	87	1000	90
100	96	2000	90
200	97	4000	81
400	89	6000	83
600	91	8000	84
800	91	10,000	84

Due to the statistical nature of the music, the sounds in the various frequency regions combine to give a peak level at the conductor's stand of 115 db. It is seen that this is 18 db above that in the single critical band which gives the highest level, namely around 200 cycles.

It is assumed that equipment can be designed that will reduce the hum and other amplifier noises to levels below that inherent in the film or tape. Very careful engineering can accomplish this. There are now available magnetic tapes capable of recording wide ranges of frequency and intensity.

Table II. Range of Possible Levels on Magnetic Tape: Standard Signal to Noise = 47 db.

Frequency (cycles/sec)	Range (db)	Frequency (cycles/sec)	Range (db)
50	15	1000	65
100	30	2000	65
200	45	4000	60
400	55	6000	45
600	60	8000	31
800	64	10,000	18

However, one cannot get the information for design purpose when only one number is given for the signal-to-noise ratio. For example, Table II shows some measurements on a popular magnetic tape recorder.

The company manufacturing the tape recorder gives the signal-to-noise ratio of 47 db as per SMPTE standard specifications. The numbers in Table II under range give the difference between the maximum level of a reproduced pure tone without the standard distortion, and the level at which the same tone can just be distinguished in the tape noise. The latter level is known to be equal to the noise level in a critical bandwidth.

Some of the very best magnetic tape recorders have an advertised signal-to-noise value of 60 db. Therefore, in the absence of any of these data the method of reaching a design will be illustrated by assuming that 13 db may be added to the levels in Table II to give values for the best tape and machines now available.

The first step in the design is to choose amplifiers, post-equalization networks and loudspeakers so that when these are connected to the reproducer, the level of the noise in each critical bandwidth reaches the audience at the audience noise levels shown in Fig. 1. The last statement makes the problem too simple, for this adjustment cannot be made for all positions in the audience. If this adjustment is made for the center of the audience then the noise may or may not be objectionable to those near the front. An engineering judgment must be used and will be influenced by what one is expecting to attain.

If the center of the audience is used as the criterion, the highest levels which can be reproduced at the center of the audience by the best tape and without automatic gain controls are shown in Table III.

Table III. Possible Levels of Pure Tones Reproduced Singly.

Frequency (cycles/sec)	Pressure level (db)	Frequency (cycles/sec)	Pressure level (db)
50	90	1000	102
100	88	2000	100
200	93	4000	93
400	98	6000	78
600	101	8000	69
800	102	10,000	63

We must now consider whether this system can be used for reproducing a symphony orchestra without resorting to compandor systems.

Let the response with frequency from the recording-head current to the acoustical pressure in front of the loudspeakers be R_1. Then pre-equalizing networks must be introduced so that the response R_2 from acoustical pressure in front of the microphones to the current in the recording head is a mirror image of R, or $R_1 + R_2 =$ Constant±3 db. The pre-network counteracts the frequency distortion introduced by the post-network. A permissible amount of variation from a flat response may be taken as about 3 db. The frequency range covered should be from 40 to 12,000 cycles/sec. The peak levels in critical bands at the conductor's stand from a large symphony orchestra are shown in Table IV.

Table IV. Peak Levels in Critical Frequency Band at Conductor's Stand From a Large Orchestra.

Frequency (cycles/sec)	Pressure level (db)	Frequency (cycles/sec)	Pressure level (db)
50	87	1000	90
100	96	2000	90
200	97	4000	81
400	89	6000	83
600	91	8000	84
800	91	10,000	84

It is seen that these possible levels are only 6 to 9 db below the podium levels of from 400 to 4000 cycles/sec. In this range, the levels at the center of the audience could be about the same as those produced by the orchestra if it were present. But there are serious deficiencies outside this range. I have gone into this much detail to show the importance of giving the signal-to-noise ratio of a given recording medium as a curve going from 50 to 10,000 cycles/sec, the ordinates being the maximum level of pure tone that can be recorded minus the level of the noise in the critical-frequency band centered at the frequency of the recorded tone.

In the absence of a better recording medium certain compromises must be made.

Assume that 10 db below podium levels will satisfy an audience. Then in the range from 400 to 4000 cycles/sec there is a small margin to spare. In the lower range let the distorting network be arranged so the levels at 50, 100 and 200 cycles/sec, are 5, 16 and 12 db with respect to the original design. At these frequencies the tape noise will be these amounts above the audience noise. At the higher frequencies one could compromise two ways: (1) let tape noise rise above audience noise, and (2) do not try to reach levels which the orchestra produces. For example, at 6000 cycles/sec let tape noise rise 10 db above audience noise and let response drop 3 db; at 8000 cycles/sec let tape noise rise 15 db above audience noise and let the response drop 24 db.

This would give a fairly good system. Enough has been said to show the necessity of starting the design by first determining the capabilities of the recording medium. If one wanted to reproduce the levels at the audience center equal to those at the podium, or make them even 10 db higher for enhancement purposes, a compandor system would be necessary such as was used

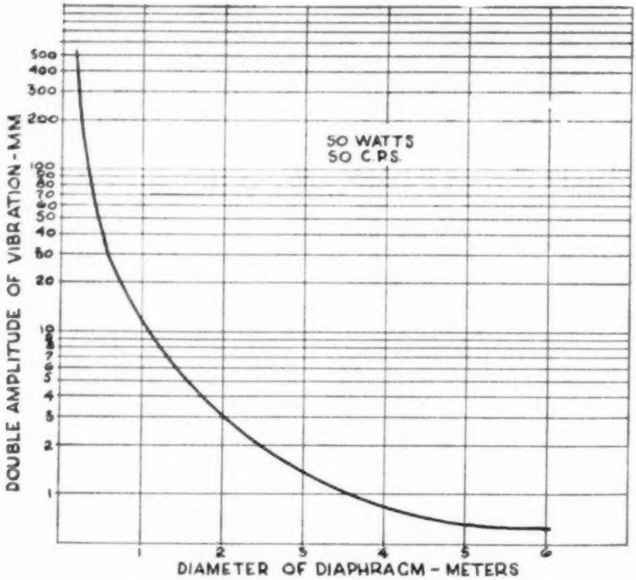

Figure 2

in the first Bell Telephone Laboratories Stereophonic System. A 20-db compandor will give these conditions with the compromises described above. A 30-db compandor is easily constructed and can be used to decrease the compromises given above by 10 db.

The mechanism of these compandor devices will raise the tape noise levels only when the signal levels are high. So, in general, the noise will not be heard. But there is a "hush hush" effect, the noise rising and falling as the sound level rises and falls, which can be heard especially when the sound power is located in the high-frequency range. This "hush hush" can always be heard when the signal being recorded is not delayed in time compared to the signal operating the gain controls. A simple way of obtaining this delay is to place the microphone operating the gain controls from 6 in. to 2 ft, depending upon how fast the gain controls operate, closer to the orchestra or sound source to be recorded than the microphone picking up the signal.

When using the compandor system a separate recording channel must be used called the control track. In the Bell Laboratories System, three carrier currents, which were modulated in the proper way and recorded on the control tract, were used to control the gains in the three signal channels.

The acoustical power requirements may be stated simply. To produce the same output as the orchestra requires a peak of about 70 w of acoustical power, to have an enhancement of 10 db requires 700 w. This was the design objective in the first Bell Laboratories System. Most of the elements for such a system as described are now readily available. Suitable microphones, amplifiers, elements for building the distortion networks, and compressors and expanders can be purchased on the open market.

The low-frequency loudspeaker required to meet the above design objective

deserves special mention. When the music is enhanced 10 db, each of the low-frequency units may be required to radiate approximately 50 w in the 30- to 100-cycles/sec region. The requirements for this amount of power at 50 cycles/sec from the mouth of a large horn or from a very large circular diaphragm are shown in Fig. 2.

The abscissa gives the diameter in meters of a circular radiator placed in a baffle, and the ordinate gives the amplitude of vibration of this radiator that will create 50 w at 50 cycles/sec. Consider first direct radiators. If one selects a 40-cm cone diaphragm, which is about the largest that can be made to move readily as a unit without breaking into segments, it would need to move to and fro 65 mm every 1/50 of a second. A designer immediately recognizes that this cannot be done with the materials with which he is familiar. It is estimated that the maximum double-vibration amplitude which is usually achieved without distortion is about 3 mm. With this amplitude the diameter of the radiator as seen from Fig. 2 must be 1.9 m. The designer then recognizes that to make such a large diaphragm vibrate without breaking into segments would require a very elaborate driving mechanism and would therefore be very expensive. But, it probably could be made.

Probably an easier way to achieve the same result is to use a number of small cones placed as close together as possible in a circular cluster and mounted in a baffle. Care must be taken to make them all vibrate in phase. If cone diaphragms 40 cm in diameter are used, 25 of them would be required and each one must be designed to produce a maximum double vibration of 3 mm. This seems to be a feasible way of achieving the design objective. If such loudspeakers were not clustered in a baffle but placed at random throughout the auditorium, many times this number would be required. When the loudspeakers are clustered the radiation impedance of each is tremendously increased. Instead of the 25 vibration units the objective may be obtained with a horn having only one of these vibrating elements. This would necessitate a horn 10 or 12 ft long with an area at the mouth of about 40 sq ft.

The Bell Telephone Laboratory's low-frequency speakers used in the demonstrations mentioned above radiated 25 w in this low-frequency range with about 70% efficiency.

Due to the size, weight and expense of these projectors, either the direct radiator or the loudspeaker type, a compromise from these ideals has always been made. These compromises represented good engineering judgment for most purposes but such loudspeakers will not produce the low frequencies with the powers indicated in our objective. We all know that musicians want more bass rather than less. Let us hope that in this venture into wide-range pictures and stereophonic sound the necessary loudspeakers which are required to project adequate low-frequency musical sounds will be used.

Discussion

Bart Locanthi (*California Institute of Technology*): If an initial recording is made with nondirectional microphones of essentially infinitesimal size and then the same recording is reproduced, but with loudspeakers that have directional characteristics different from those of the microphones, these large loudspeakers necessarily being very directive in the frequency ranges of interest, what troubles do you foresee?

Dr. Fletcher: Well, in the first place, you don't have true reproduction, as I pointed out, unless you have an infinite number of microphones and loudspeakers. Now, it turns out that when you're away from the stage, 20 or 30 ft, the size of the loudspeaker seems to make no difference. Of course, it would if you were up close. There would be a real difference.

Edward Stanko (*RCA Service Company, Camden, N. J.*): I was very interested in

your remarks about volume range, and am wondering whether the objectives that you set up there aren't quite difficult to meet in the average type of theater. In running *Fantasia* about ten years ago we had an amplifier system which would provide a gain change of 70 db, and 300 w of audio power; however in theaters having a 1500- to 1800-seat capacity we had to limit the gain change to about 30 db, and finally, in some cases, had to limit it to about 26 db. There were scenes, like the earthquake, which almost scared the people out of the theater. So I'm just wondering if we should insist on such high volume range.

Dr. Fletcher: As I've said, what I tried to do here is to give you a method — how to go about it. And I used as the material an orchestra. Now when you find out what it is that you want to reproduce, then you have to go through this same process and if you want to reproduce everything, there's no alternative as far as I can see, except to use the wide range of intensity levels. Since no one wants to design to such a wide range, you must design to the particular thing you want to use it for. And I know that there will be compromises. There wouldn't be any need for engineers if we didn't need compromises. It's the one that does the wise compromising that succeeds best.

W. R. Holm (E. I. du Pont): I'm wondering if your 50 to 10,000 cycles isn't a compromise in itself?

Dr. Fletcher: Did I say 50 to 10,000? I meant 40 to 12,000 — that's in the paper.

Mr. Holm: It was 50 to 10,000 on the slide.

Dr. Fletcher: I'm sorry. I think that has been fluctuating. I looked at all the data and I think, as a design objective, I would be satisfied in going from 40 to 12,000 cycles with plus or minus 3 db in level. You wonder where I got that figure, but I think that it is the amount that is just detectable. One cannot tell the difference between a flat response and one which varies plus or minus 3 db.

R. T. Van Niman (RCA Victor Div., Camden, N. J.): Extremely low-frequency sounds are produced in nature by relatively small instruments. Even the kettle drum isn't as big as your bull horn was. Why is it so much more difficult to reproduce low-frequency sounds than to produce those sounds? Is there some basic particular reason for it?

Dr. Fletcher: No, I think that your first premise was wrong. All low-frequency instruments are big. They're not small. They're the biggest instruments in the orchestra. In some instruments one is able to get larger amplitudes of vibration than one can get from a diaphragm reproducing them. For example, in an organ the amplitudes at the end of the organ pipes are very large. Then, of course, you have many low-frequency instruments in an orchestra. A thousand bass viols would still be insufficient for most conductors.

Mr. Van Niman: The real limitation, then, is in the amplitude of the vibrating members?

Dr. Fletcher: That's right. As I pointed out, you could reach the level by using a single diaphragm if you could vibrate it 65 mm.

John E. Volkmann (RCA Victor Div., Camden, N.J.): Would you give us an estimate as to the difference in level that you feel would be the requirement if we set them up not on the basis of what it is at the podium, but in the center part of the auditorium?

Dr. Fletcher: Well, I tried to indicate that, but I think I got lost because of lack of time, and left out part of the paper. You can, with the present magnetic tape, if it's as good as that assumed in the paper, reproduce at the center of the hall a large orchestra, like the Philadelphia orchestra, at full power, and make it sound as loud as it would sound at the center of the hall, if the orchestra were present. The objective I set up, you remember, was to make it sound as loud at the center of the hall as it usually sounds at the podium where the conductor is. And that is a very different objective. You'd have to compromise even in this case on the low and the high frequencies in the way that I mentioned. For the middle range of frequencies it is ample, without using any compandors. Does that answer your question?

Mr. Volkmann: Not exactly. What difference in level is there between the podium and the center in db? Is that 13 db?

Dr. Fletcher: About 10 db. I took the actual level, on the average, of an orchestra at the conductor's stand. At about half-

way in the audience, it is about 10 db lower.

Francis Oliver (Imperial Productions): Have you found that the average layman audience enjoys and can stand to hear a higher level from a live performance than from a reproduced performance? I have noticed that not only the layman, but many of the very fine professional musicians, such as some of the outstanding conductors, in listening to playbacks and equipment in their own homes, have the levels quite reduced from those they are used to hearing at the podium. One particular example — I did some recording work with Dr. Luschke of San Francisco, and he had quite a phobia about listening levels; they probably were at least 20 or 30 db less than what he was used to listening to at the podium.

Dr. Fletcher: We made some experiments on that point. When you have a monaural system, that is, single-channel system such as you ordinarily listen to in the home, you can't have the levels anywhere near as high as when you have a three-channel system. When you have a three-channel system it doesn't sound harsh, like the single-channel system does. The minute you get the level up on a single-channel system it begins to sound harsh, and that's what the musician objects to. It is our experience that when one uses a three-channel system this harshness disappears and very much higher levels are tolerable.

Mr. Oliver: Then you feel that with the three-channel system the average audience would stand for the same levels as the original?

Dr. Fletcher: Yes. However that is a matter for the musician to decide. But the above was my experience and the experience of a lot of the people at the Bell Laboratories who love music. They could tolerate and enjoy much higher levels than the orchestra could reach. The direct orchestra seemed rather ordinary after hearing enhanced music which went 10 db above what the orchestra could do. Also remember, enhanced music can be made much softer as well as much louder than the music direct from the orchestra. The dynamic range then becomes very much more spectacular and vivid.

Mr. Oliver: I hardly think they represent the average listener. I know that amongst my friends and myself the above-average levels are enjoyed, but the public seems to like the lower levels.

Dr. Fletcher: The only thing I can come back with on that is to say that the first time electrical recording for the then Victor Talking Machine Company was developed they said they didn't think they could use it because it didn't sound like a talking machine. It sounded too natural. Now, you have the same thing in audiences. Audiences are conditioned and they have to be reconditioned before they'll completely enjoy the possibilities of this new medium.

Mr. Stanko: Most of our discussion has been about orchestras. I think from practical experience you'll agree that there are certain people in the theater, like women and children, who are scared by these extreme volume ranges. I think that this should be given some consideration when recording scenes with thunderclaps and loud noises, etc.

Dr. Fletcher: I agree to that, but on the other hand I'd like to eliminate a lot of television which scares people, and not by using loud sounds.

[The following comment is by the speaker who followed Dr. Fletcher on the program.]

Lorin D. Grignon (Twentieth Century-Fox Film Corp.): Dr. Fletcher has certainly set the pattern for recording and reproduction of stereophonic sound. I want to go into one point regarding something that Dr. Fletcher said. He stated that if you wish to obtain vertical directionality, with regard to an orchestra or whatever medium you had to record, you might need nine microphones and nine loudspeakers. I think we'll be able to demonstrate to you later this week that with three channels and three microphones you can still get these up and down effects quite adequately.

Dr. Fletcher: Such a system will give about the same quality of stereophonic sound as a horizontal two-channel stereophonic system.

Experiment in Stereophonic Sound

By LORIN D. GRIGNON

This paper reports an extension of the theory and methods of stereophonic recording and reproduction, as particularly applicable to motion pictures. Microphone technique becomes very different from that previously used because of the manner of staging, the use of varied angles of view by the camera, and a fixed theater picture size. Typical microphone technique is illustrated and re-recording with added sound effects is described.

THE THEORETICAL BASIS of stereophonic recording and reproduction is rather generally known. However, for convenience, it will be restated as follows: If an infinite number of ideal microphones could be placed within a three-dimensional region bounding a source of sound energy, each microphone being connected to a distortionless transmission system terminated in an ideal reproducer at some other location in surroundings identical to those at the source location and in space relation to each other as their corresponding microphones, then an observer at the distant location would experience the same sensation as an observer at the source point. The first compromise to the ideal situation considers microphones and reproducers in two-dimensional space as an acoustically transparent curtain between the source and the observers. The second compromise employs an infinite number of microphones in a single straight line. It has been found that three complete systems give a good subjective approximation when three microphones are equally spaced along some straight line in relation to the source. Complete descriptions of experiments in this direction are given by a Bell Telephone Laboratories monograph.*

†[A comparison between conventional single-channel, binaural and stereophonic systems can be stated in the following manner: Single-channel methods intend to transport *all listeners of an audience to the same microphone location and do this as though they were one-eared;* binaural systems transport *all listeners of an audience to the same microphone location but permit them the use of two ears;* stereo-

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* A major portion of those papers is presented in this issue of the *Journal.*

† This paper consists in large part of a previous paper presented by the author on May 18, 1948, at the Society's Convention at Santa Monica, Calif., and published in the *Journal* for March 1949. Additions to the original paper are shown throughout this publication by enclosing them in brackets [ ].

phonic methods transport the *original performance to the location of the ultimate audience*. The differences are subtle but important.]

The work reported here is an extension of the theory and methods for the use of stereophonic sound in motion pictures. The opportunity to investigate this possibility came about by a desire on the part of Twentieth Century-Fox management to evaluate possible technical improvements in motion pictures. Western Electric Co. cooperated through Electrical Research Products Div. by supplying film recording and reproducing equipment and other technical assistance.

Methods were devised for recording dialogue and music for use in motion pictures, without basically changing accepted fundamental forms which include the use of long, medium and close shots and intercutting techniques. This is not to say that present cutting philosophy for stereophonic motion pictures is entirely suitable, as there is evidence that indicates some new approach is needed. Re-recording, with added sound effects, prescore and playback methods were all used. The end result of the experiment to be described was the production of two single-act plays, several full-orchestra numbers (one with picture), and a vocal rendition with accompanying orchestra.

It was concluded that stereophonic methods, with suitable modifications, can be applied to motion-picture technique and result in a sound presentation considerably superior to methods now in use.

Microphone Technique Development

The problem of pickup, particularly for dialogue, was first approached by setting up a three-channel monitoring system, using the amplifier and horn apparatus as installed in the test theater, and providing microphones and mixer equipment in an adjacent stage. On this stage a small living-room set was constructed and pickup tests were begun using stock players from the studio roster.

It was natural first to try the accepted method of having three microphones equally spaced and placed in some straight line in relation to the actors. This method failed immediately—the reasons being as follows:

1. The action was taking place in a restricted space.

2. Seminondirectional microphones were essentially useless because of the proximity to the sources and to acoustic reflections from parts of the set which produced false apparent origins.

3. Actors generally play to other actors and do not face an audience as do public speakers. Methods were needed for giving sound placement to actors who are speaking at right angles to the camera axis and within a few feet of one another.

4. Since various camera lenses are used to give emphasis or localize action, magnifications or distance distortion exists and a similar effect was necessary in the sound pickup. [To explain both sound spreading, or magnification, and the necessity for knowledge or standardization of loudspeakers as related to the picture frame consider Fig. 1* and the following:

[Scene A is assumed to be a large set and the camera angle is chosen as shown to include almost the entire scene. Further, assume the ultimate

* In all the illustrations to this paper: actors are shown by a "V" within a circle, the point of the letter indicating the speaking direction; microphones by a circle with the protruding arrowhead indicating the direction of maximum pickup and the extended tail the direction of minimum reception, the inscribed letter indicating left, center or right; and movement of actors or microphones by dashed lines with arrowheads giving direction.

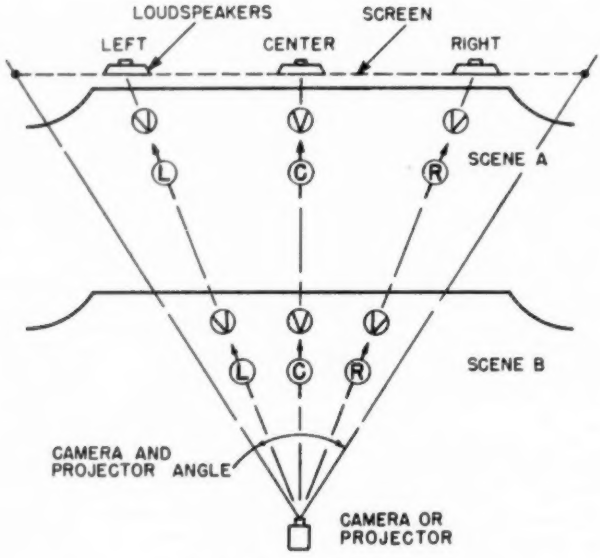

Fig. 1. Sound spreading.

screen upon which this scene is to be projected is of the same physical dimensions as the scene so that the horizontal projection angle is the same as the camera angle. In this case the original scene is recreated life size. This is shown by superposing the screen and projector upon the set plan. For purposes of illustration, the loudspeakers behind the screen are shown spaced at 1/3 screen width center-to-center and lines drawn through them to the projector.

[It is understood that each microphone is separately connected eventually to a corresponding loudspeaker. If the reader will now examine the relative positions of the actors and microphones it will be obvious that an actor anywhere along one of the lines drawn through the loudspeakers must be picked up principally by the microphone associated with the loudspeaker being considered. If the relation of the loudspeakers within the image frame is something other than shown, the microphone positions must also be similarly disposed, otherwise the relative localization of the reproduced sound will be different than that of the original.

[Now, if the camera were moved closer to the set, and the camera lens not changed, a smaller portion of the set would be photographed. For convenience, this is depicted in Fig. 1 by moving the set closer to the camera (Scene B). This scene occupies the same film frame and in the same theater illustrated the picture will now be greater than life size. Above, it has been said that microphones must be located on or near a line intersecting the associated loudspeaker and the camera or projector, therefore the microphones for Scene B are physically closer but the sounds when reproduced are, in effect, spread. By separating microphones farther apart than dictated by the loudspeaker positions, the sound localization can be minimized or squeezed together. Thus, the principle of sound spreading may be explained. As a

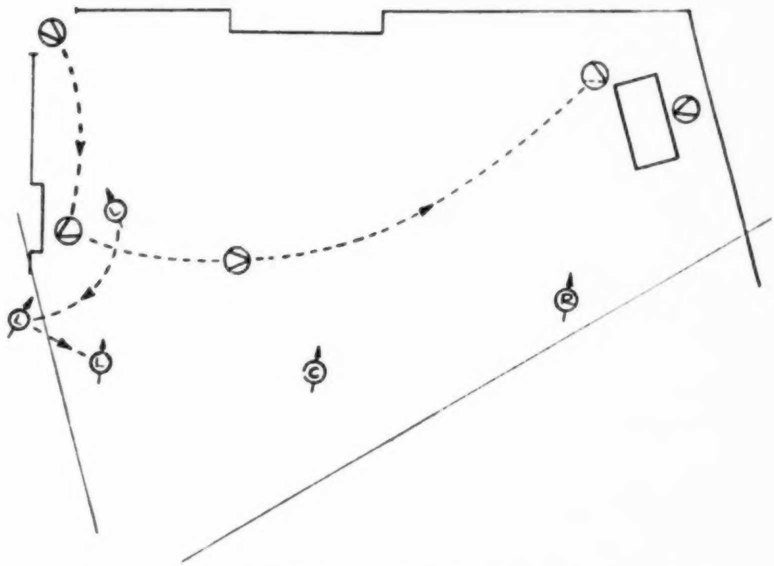

Fig. 2. Typical microphone arrangement for large-set long shot with broad actor movement.

final point, whether the picture is projected to any particular size is immaterial because it is the relative positions which are important; the initial life-size projection shown in the figure was chosen only for convenience.

[5. The practical aspects of set and recording-system noise sometimes demand closer pickup than that dictated by classical stereophonic pickup theory. Further, intelligibility is of paramount importance so that the dialogue can be understood under the adverse conditions represented by the variety of motion-picture theater equipments and auditoriums.]

Using adjustable directivity unidirectional microphones and separate microphone booms for all further work, several basic microphone setups resulted.

For purposes of definition, consider a source which emits sound continuously and which is in constant movement, then the reproduced sound must also move continuously in the same way without obvious dwells or jumps from position to position and this characteristic will be termed smooth sound placement transition.

The usual equidistant, in-line microphone technique can be used in long shots of large sets with wide separation of actors and broad movements. Even then, to have smooth dialogue transition, some microphone movement may be required, as illustrated in Fig. 2.

[Why was microphone movement required in this set? The actor entering from the left was too distant for intelligible recording under the conditions of set and system noise, but if the microphone had been too close, the distance perspective would have been completely lost. Secondly, when this same actor proceeded to the far left position of the set and directed his dialogue towards the wall intelligibility was again too poor, although the loudness was sufficient to overcome noise satisfactorily. Hence the microphone was moved about in

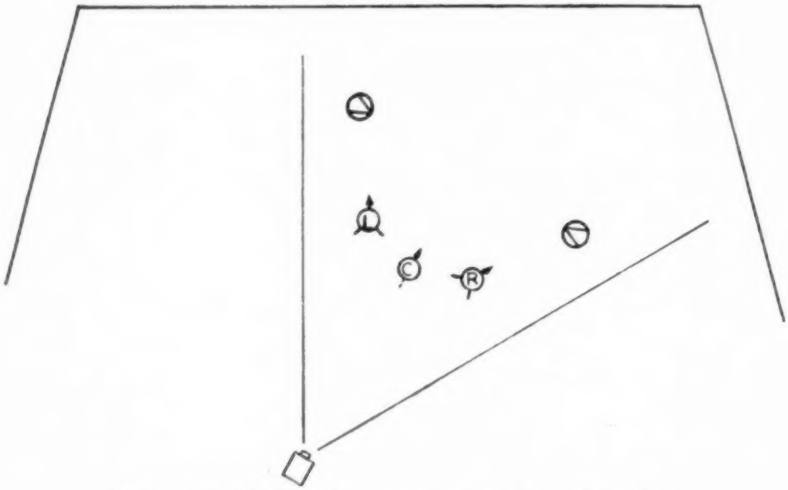

Fig. 3. Typical microphone arrangement for medium shot.

order to pick up more direct sound than it would otherwise have done. The final lateral movement placed the microphone in the correct position for picking up the dialogue as the actor crossed the set. There is a refinement which should be noted because it is not obvious in Fig. 2. If the actor speaks dialogue from the beginning of his movement to cross the set the microphone movement, or "pan," should be slower than the movement of the actor so that sound movement results which fits the picture. This kind of microphone movement is frequently encountered. It is interesting to observe that this kind of setup — a long shot — is one of the easiest in stereophonic recording, contrary to the experience of single-channel recording.]

This method is also generally used for recording of effects. One experiment using such a pickup consisted in recording airplane takeoffs, wherein the microphones were placed along the runway. The microphones were spaced 150 ft apart.

When actors are not disposed closer than 6–7 ft and are speaking directly to each other, the setup of Fig. 3 is used. Should either turn or move away and speak lines, then microphones must be moved accordingly. For example, should the right-hand actor turn 180° and speak lines, then the R microphone must be moved sufficiently to the right to give good pickup and the C microphone readjusted to a somewhat central position, probably favoring the right-hand actor. Also, dependent upon set conditions, it is sometimes necessary to adjust the null directions of the L and R microphones on the opposing person. This change in pattern does not eliminate pickup into any microphone so adjusted, because the null is imperfect and sufficient energy arrives from other directions, thus satisfactorily meeting necessary pickup requirements.

[It is quite apparent that in this setup sound spreading will result. Note that the center microphone is pulled back slightly which serves to assure no "jumping" of sound from either side to center. If a center source existed in this scene it would probably have been necessary to have the center microphone further out or to move it

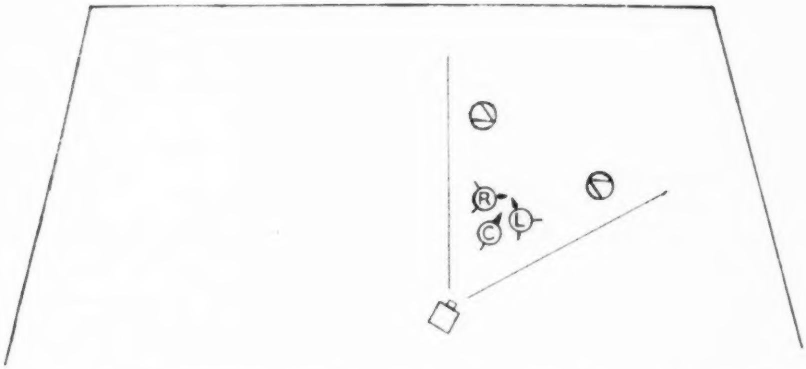

Fig. 4. Typical microphone arrangement for close shot of two actors requiring "sound magnification" or distance distortion. Note crossed-over placement.

out only at the time that it was required for good pickup and to retract it as might be necessary to protect the dialogue from the side actors.]

In many instances microphones were grouped in a cluster tighter than shown in Fig. 3. This condition, carried to its limit, occurs where a close-up of two actors is used who are physically separated by only 3–4 ft and farther, they will appear on the screen to be 8–10 ft distant from one another, resulting in the crossed-over configuration of Fig. 4. Note that the L microphone is placed on camera right but is actually picking up the left-hand actor, provided of course that it is adjusted to minimize pickup from the right-hand performer. The R microphone is, of course, also reversed as indicated. This, obviously, is one of the most difficult types of pickup, as the microphone positions must be carefully chosen, the directivity nulls correctly used and, in particularly bad cases, the relative channel gain adjusted. It is sometimes wisest to abandon sound placement under these conditions and use the condition of Fig. 5, which is an effective means to maintain stereophonic quality without the feature of sound-origin placement. By proper choice of dimensions, unwanted sound placements can be eliminated. Average dimensions might be 5 ft on each side of the triangle and 3½ ft on the base.

Manifestly, it is no longer permissible to revert to the demands of early sound motion pictures that actors be fixed at specific positions for the delivery of dialogue. Therefore, motion of microphones is required. Combinations of all the microphone configurations shown in the preceding figures have been used in many of the scenes recorded. The principal problem is one of smooth transition and proper apparent sources.

Two interesting and useful effects, not possible without stereophonic methods, have been used. The first creates the illusion of an actor talking and moving within the set but never being seen while the camera showed a small portion of the set and another player. This offstage illusion can be created by sound unassisted by the visible actor who, without stereophonic sound, must describe the unseen action by following with his eyes. The second is the ability to make sounds from either side apparently very much offstage.

[The reader may wonder how this can be done if there are no microphones or loudspeakers located far to the side of the picture area. Briefly, as a sound

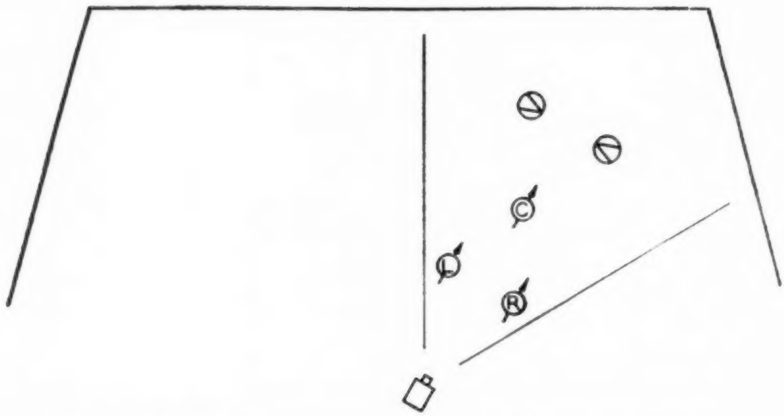

Fig. 5. Microphone arrangement to maintain stereophonic quality but without sound placement other than center screen.

source recedes laterally away from the microphones the intensity differences and ratio of direct-to-reverberant sound of the pickup decrease although the average of the reverberant sound is increasing. It can be seen that the pickup situation for offstage sounds is certainly different than for those onstage.]

Recording and Reproducing Equipment

The equipment used consisted of three essentially identical recording channels with a common film recording machine, placing three 200-mil push-pull variable-density tracks on a single 35mm film. The three modulators were arranged in an arc, the two outside optical paths brought parallel with two sides of a front-surface prism, and the center path passed through a hole in the same prism. Separate objective lenses were used for each modulator with a single cylindrical lens near the film for all channels. Pre- and post-equalization were utilized.

Monitoring was provided by earphones where each side channel was connected to single reproducers on respective ears and the center channel was split to both ear receivers in such a way as to supply 3 db less power to each ear than the corresponding side channel, the total power from the center channel being the same as the side-channel outputs. Further, the side-to-side cross-feed was not permitted higher than −25 db from the direct source.

The film reproducers used a single exciter lamp, a fixed-aperture plate with large radius of curvature over which the film passed to maintain contact for focus, a single objective lens, three engraved slits, and associated photocells arranged in an arc to provide equal optical path length. Filtering was similar in principle to the newer mechanisms now being supplied and essentially equal in effectiveness.

The sound reproducers were two-way systems of good characteristics. One was located at screen center and the other two placed with their axes 1/3 screen width off-center. These dimensions are not inviolate. The best arrangement is determined by existing conditions and desired effect.

Re-Recording

In connection with one two-reel playlet which was used, it was necessary to add horse-hoof sounds, footsteps, cup crashes,

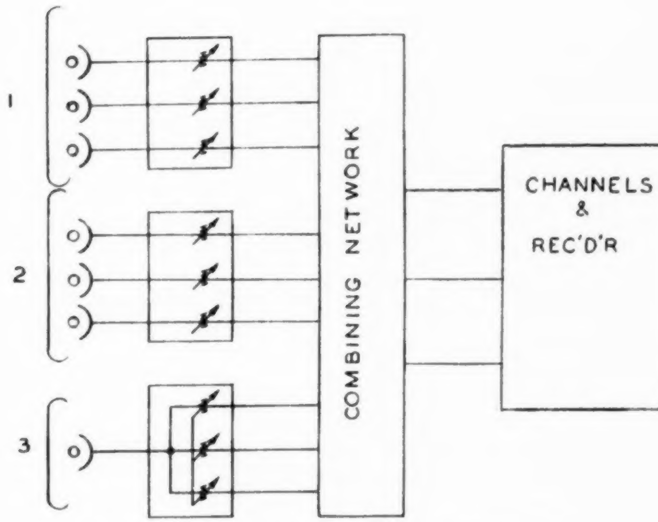

Fig. 6. Block schematic of re-recording equipment.

and shots. All these effects, except the cup crashes, were re-recorded from stock library material. The equipment arrangements are given by Fig. 6. Note that mixers 1 and 2 are conventional 3-channel stereophonic units. Mixer 3 is a special control designed to transfer the single input to any of the three channels or to any two adjacent channels, meanwhile maintaining constant total power. With this control it is possible to move a single source smoothly back and forth to create any desired illusion.

By the use of the special control, offstage horses were made to sound as though they approached from a distance to the left and came to a point just off stage, also gunshots and footsteps were added and properly placed.

The use of re-recording retained the advantages of level smoothing and permitted a small amount of placement correction. Dependence cannot be placed on re-recording for changes in placement of original material because placement, except in certain special cases, is not primarily due to intensity differences. This point is developed more fully later.

[Due to the added complexity of adding movement to effects from monaural tracks it is fortunate that sound records may now be combined satisfactorily using available magnetic-film methods, even if several generations of re-recordings are required. The movement of several effects might be introduced one or two at a time. Regarding effects, it is very likely that the realism of the picture can be greatly enhanced if some of the more important effects are specifically created and recorded to fit the picture. The production group must of course weigh the showmanship value of the improvement against the probable cost.]

Music and Vocals

Large orchestras (90 to 100 pieces) were recorded within a regular scoring stage. It was desired to obtain good separation of instruments and due to the compactness of the arrangement, unidirectional microphones were again

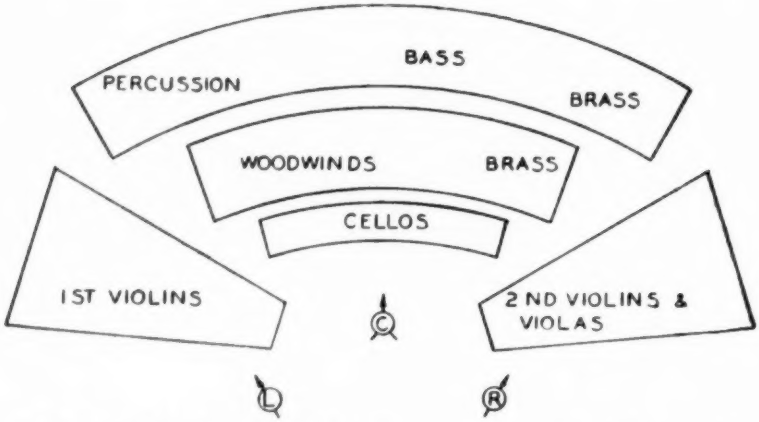

Fig. 7. Typical orchestra and microphone arrangement for a large group in a particular scoring stage.

used, placed in a relatively close group. This also helped to minimize troubles due to room acoustics causing false origins. A typical setup is shown in Fig. 7.

[Playback or prescoring presents a problem. There are three apparent ways by which this might be done, as follows: on-set recording, pre-planned recording or temporary recording later replaced. Experience has taught that the first of these, on-set recording, is very costly and does not usually yield the best recording fidelity. Preplanned recording is quite feasible if the producer or director can accurately decide what scene he will photograph and what camera angles will be used and will then carry out the plan. Once the music has been recorded with instrument placement to fit the indicated shooting plan, there cannot usually be much alternative even though the director later recognizes better situations. The third method allows complete freedom. The temporary recording need not be stereophonic nor perfect in performance provided it has the desired tempo. The temporary track is used for the playback and, after the picture is finally edited, used as a guide track for the recording of stereophonic music which fits the final picture scenes.]

The recordings obtained from one such session were used for playback and the orchestra photographed in a large set. Various cuts and angles were used and it was necessary to exercise caution to select angles and musical passages which were compatible. In some instances minor sacrifices to correct sound placement were made to provide adequate camera freedom. [This music recording had not been preplanned because there had been no intention to photograph the orchestra.]

One vocal number was recorded experimentally at the time a regular production prescore and vocal-recording session was in progress. The vocalist was performing in a small vocal booth with the orchestra in the adjoining scoring stage. A separate microphone was provided for the vocalist and a stereophonic pickup of the orchestra arranged. The vocal and center-channel music microphone outputs were mixed at the time of the performance, thus obtaining monaural vocal always on the center channel and a stereophonic record of

the accompanying orchestra. This track was later used for playback and the actress photographed, but since the vocal existed only on the center track it was necessary to frame the action so that the performer was nearly always center screen.

[When prescoring for playback it is usual practice, for good reasons, to record the vocalist and orchestra on separate tracks which are combined later in the re-recording process. If it is at all possible, planning the scenes before recording will permit all the advantages of stereophonic recording for both the vocal and the orchestra. It is not always true, but generally so, that the orchestra is not seen in the picture, and in these cases the orchestra may be recorded as though it were located in a theater-orchestra pit and being heard from all over the screen with good quality. Another method for handling vocals involves the use of the quiet (supersonic) playback reproducing the orchestra to the vocalist and recording the latter on the set during the shooting. The third method utilizes a single-channel recording of the vocalist for playback and timing which is later replaced by a true stereophonic recording which fits the final picture as to placement and perspective. The fourth, and least desirable so far as realistic reproduction is concerned, uses a single-channel recording which is used for playback, and during re-recording is transferred to three sound records to give direction, or placement, to suit the camera view. The last method sacrifices all the advantages of stereophonic recording except the directional feature, and it must be noted that the improvement in quality obtainable with stereophonic methods is most apparent in musical recordings.]

It was noted that orchestra levels greater than normal could be used without destroying the effectiveness of the vocal selection. This might be explained as follows: The vocal is always reproduced as a single direct source and is audibly compared to a stereophonically reproduced accompaniment, thereby increasing the perceptible aural differences and subjectively providing greater separation. No work of this type was done with both sources recorded by stereophonic methods and until this is done and compared to the method reported here, no final conclusion can be reached.

General Observations

Since this experiment was an integrated project involving all present motion-picture production methods, demanding close correlation between each contributing group, it was possible to evaluate the effect that stereophonic-recording application might have on motion-picture production and presentation in general and various phases in particular. Those effects, and other observations based on the work herewith reported and which presently seem of the greatest importance, will now be discussed.

From the microphone-pickup work come three cardinal points; sound placement matching corresponding picture, smooth placement transition of the sound from a moving source, and a third point not previously mentioned, that to avoid major changes in quality some sound must be picked up in all microphones at all times.

The requirement of correct sound placement is obvious. It has been found that sound-intensity differences do not play the major role in determining placement except under unfavorable acoustic conditions. Those situations in which high-intensity directive reflections occur and are then picked up by a microphone other than the one closest to the source create the exceptions. Under such circumstances there exists only a small intensity difference between the nearest and other microphones and an otherwise minor change in intensity adjustment can introduce a change in

placement. With suitable acoustic conditions, intensity differences due to equipment maladjustment of 6–10 db do not destroy localization but loudness is of course affected. These observations would indicate that the greater contribution to sound placement is caused by phase differences which are a complex function of acoustics, frequency, and ratio of microphone spacing to frequency.

[There are, however, situations where intensity differences are of principal importance. In general, close shots with small physical displacements of the microphones are most critical of intensity balance with the opposite true of the long shot or wide set.]

Smooth sound transition is necessary, otherwise sudden placement jumps occur which are very disturbing to any observer after a short acquaintance with stereophonic reproduction.

The third point concerning quality is related to the inherent improvement in stereophonic over monaural methods. It has been demonstrated that a two-channel stereophonic system does not provide the quality improvement afforded by a three-channel arrangement, as might be expected since the former approaches closer to the inferior monaural condition. The quality difference between two- and three-channel systems is such as to establish the foregoing statement concerning pickup in all microphones.

In connection with recording on a production basis two specific items of equipment were greatly needed. The sound mixer should have a picture monitor displaying the scene the camera is photographing. This apparatus will shorten rehearsal time and guarantee sound and picture match. Such devices are now available by television technique and are rapidly approaching practicality for motion-picture use. Second, a better mechanical device than presently used microphone booms must be devised. Some combination of mechanisms which could permit microphone movements with fewer personnel is highly desirable, not only for the sake of reducing manpower costs but to minimize errors caused by lack of coordination.

Film editing must be considered when using stereophonic sound. Directors, photographers and editors are ever watchful of camera angles and actor movement to facilitate smooth cutting, and stereophonic recording demands the same consideration. Much of this problem is automatically solved when the visual action is properly done, but consider the effect of an offstage voice from the left when the offstage person is shown, in the very next cut, on screen right. When cutting pictures editors always strive for action which flows smoothly and logically unless spectacular effects are desired and these are then introduced deliberately. Exactly the same situation exists with stereophonic recording. With proper understanding "jumpy" effects can be eliminated or purposely used when apt. At present, picture editing is hampered very little by sound. It may very well be that some types of cuts or cutting practice cannot be used successfully in connection with stereophonic methods, and picture may have to concede somewhat more importance to sound.

[An example of past cutting practice which illustrates this point is where sounds from other scenes, usually related to the cut picture, are used for offstage lines. Sounds from other scenes are usually placed incorrectly or have totally incorrect perspective.]

How will production costs be affected by stereophonic recording? Any answer to this question at this stage of the art requires some speculation since so many factors contribute to such costs. Expense can be greatly influenced by the degree of perfection in the result desired. Considering some of the more tangible factors, it does not appear that production costs need be increased

excessively. At no time were more than three complete rehearsals required to satisfy sound-pickup requirements. Usually one or two sufficed; one of these being necessary to observe the action through the camera finder to establish relative replacements. Rehearsal time could have been cut in half had the remote finder mentioned above been available. Undoubtedly, with greater experience, the demands of original stereophonic sound would not be much different than at present.

Dubbing costs would of course increase, since greater time would be involved to match both lip movements and action. However, the use of dubbing, while absolutely necessary in some cases, is a dodge and is best minimized.

Demands on set construction are no different for stereophonic than for monaural recordings. An acoustically good set monaurally is still a good set stereophonically and good acoustics, in general, are now sought. Actually, a saving may result in using stereophonic methods because of the poor records frequently obtained in portions of otherwise acceptable sets which, if sufficiently inferior, are dubbed or re-recording time is used up in attempted correction.

Equipment costs, which are a small percentage of production charges, would be raised two to two and one-half times.

Stereophonic reproduction in the theater naturally will require additional equipment. In the event that stereophonic methods are applied to motion pictures, some technical and economical method must be devised to supply both stereophonically and monaurally recorded film during conversion. It is even likely that such practice would continue for some time in order to supply the very small low-income theaters, and in some cases, for reduction for 16mm release.

[Some persons question whether it is worth while to use three-channel stereophonic recording methods on production. It is argued that monaural, single-channel recording, given direction later during re-recording by a "panning potentiometer" or other means, is sufficient for the purpose. Pseudo-stereophonic methods can indeed be used if the producer is willing to sacrifice the lifelike perspective effects, the showmanship of offscreen dialogue, music or other sounds and the improved fidelity particularly in sets described as "boomy," all of which are provided by true stereophonic methods. Should the producer decide to accept pseudo-stereophonic sound, he must also accept certain restrictions among which are: (1) there cannot be overlapping dialogue or sounds in a scene from more than one source which have visually different placement; (2) there cannot be moving sounds in the original scene simultaneous with fixed or differently moving sounds; and (3) if the dialogue or sounds from separated sources follow one another with very little interval, it may be necessary to cut the original sound into two or more master sound tracks so that more than one re-recording mixer may handle only that part of which each is capable.]

Conclusions

1. Greatly improved sound quality can be obtained by the use of stereophonic methods. It is easily demonstrable that recordings made in sets which give unnaturally "boomy" or otherwise poor results monaurally result in records which more nearly reproduce the true conditions in that set when recorded stereophonically. This is still true when disregarding subjective sound placement.

2. Sound placement is affected only to a small degree by individual system gain differences indicating that phase and not intensity differences play the major role in determining placement.

[Since writing the early paper it has been found that this conclusion is not

always true. There are circumstances where channel-gain differences as small as 2 db affect the placement. Therefore, it seems more correct to say that both phase and intensity difference affect placement and the relative importance of each varies with the particular situation being recorded.]

3. The three important points of stereophonic pickup are: (1) sound placement matching visible or desired implied action; (2) smooth sound-placement transition and (3) some pickup in all microphones at all times.

4. Many more illusions can be created by sound alone, opening new dramatic, effective avenues for motion-picture story presentation.

5. Just as the directions of visual action must be properly done to permit cutting, so must stereophonic sound directions be considered. Of a similar nature, since it pertains to camera angles and editing, prescoring for playback purposes should be planned to match the intended action and anticipated cutting. There is evidence that present editing practices would need modification.

[Sounds from different scenes, as for offstage dialogue, cannot be cut together for a given scene unless such sounds have been so recorded that they fit the picture.]

6. With sufficient experience and certain desirable auxiliary equipment, production cost need not be greatly increased. Two of such auxiliaries are a picture monitor (remote viewfinder) for the sound mixer and more suitable microphone-handling equipment. The degree of perfection desired would be the largest cost factor.

[Very little difficulty has been experienced in lighting, even though three or more microphones might be used. There are times when the sound engineer has considerable latitude and can ease the lighting problem of the cameraman. There are other times when very little latitude exists and the sound engineer can then give away very little to the cameraman. Good cooperation and understanding by both parties is demanded.]

7. Re-recording, technically, is no more difficult than at present but having introduced one additional degree of freedom, more manipulation will be required. Many stock library monaural tracks may be used, provided equipment is available for controlling placement of the desired sound. [Greatly increased showmanship can sometimes be achieved if specific effects are stereophonically recorded for the scene.]

8. Increased effectiveness of stereophonic sound is obtained if used with a picture of greater aspect ratio than presently used. Given a picture in which the ratio of width to height is approximately 1.75 instead of the existing 1.33 a somewhat closer approach to the horizontal angle of human vision is obtained and the relatively greater width assists sound placement by simplifying the original pickup and giving better coverage in the theater.

As with any other subject of similar complexity, no one experiment answers all the questions. Much work remains to be done. Reproduction in various kinds of auditoriums has only been superficially explored. Some of the questions will only be fully answered by actual production experience.

Contemplation of the results obtained from the described project and with a realization of remaining problems, it is concluded that stereophonic recording can be used for motion pictures and will provide a superior sound presentation which is one step closer to technical perfection and realism on the screen. Unfortunately, stereophonic sound cannot be introduced overnight but it can be made available to the industry if wanted.

[Surround, or auditorium, loudspeakers are gaining favor for special effects. Except in a few cases the sounds from the surround speakers have not been

recorded stereophonically and are frequently incompatible with the screen picture. It seems that surround effects must be used with discretion.

[There is an immediate need for a standard loudspeaker placement. This placement must be related to the screen-picture size and shape. For pictures with aspect ratios of two or greater it is herewith proposed that the loudspeakers be placed 1/3 screen width apart (center-to-center). This placement permits close-up quality over the whole scene and allows for offscreen sounds having correct perspective. If the placements are substantially wider it is not possible to place sounds correctly and also obtain close shot quality when needed.]

Acknowledgments

The welcome assistance of E. I. Sponable of Twentieth Century-Fox Films and K. F. Morgan of Western Electric, as well as several others, is acknowledged.

[The result obtained by the methods described was demonstrated simultaneously with the CinemaScope demonstrations at the 1953 Spring Convention at Los Angeles. A great variety of material was shown which illustrated most of the situations, methods and practices described.]

Discussion

Question: Have you ever tried to balance two microphones in a derby hat and use this as a pickup for sound? We have found in this way, we can get excellent reproduction, even better than with three microphones placed at such long distances. I think the reason for this is that, as you see in your picture, you will have only time differences between the microphone.

Mr. Grignon: No, we have not tried that particular combination. We assumed that a good starting point would be based on the extensive previous work referred to in the Bell System Monograph. It was our job to try to adapt stereophonic as it was then known to the motion-picture problem.

Question: During the war we were able to do much work on stereophonic sound in Holland, and I think we found a better principle to start from than you did here in America.

Dr. J. G. Frayne: If you make an error in the original, how far can it be corrected in re-recording process? How can you switch people from right to left if you do not get the original track straight?

Mr. Grignon: Possible corrections depend upon the degree of the error. If it is a minor error, you can push the intensity difference enough to make some correction, but if it is a major error, nothing can be done.

Chairman C. R. Daily: With regard to release track in stereophonic, does one require the same quality of reproduction from each individual track that we now feel is desirable from single theater tracks?

Mr. Grignon: Probably not, although let us put it this way: If a major change of this kind were to be made, certainly we should take advantage of the opportunity to try to increase the fidelity of recording and reproduction. These three channels were somewhat better in quality arrangement than are commonly used. With three channels, let us say, of the ordinary type now used, the subjective quality in reproduction would still be much better than we now have. On that basis, we could take less and still come out equally well.

Discussion at 73d Convention

George Lewin (Signal Corps Pictorial Center): Is this a triple sound track recorder?

Mr. Grignon: At the moment yes. However, as far as CinemaScope is concerned we intend to provide a composite release in which picture and sound will be placed on one piece of 35mm film.

Mr. Lewin: Well, shall I take it then that you edit directly from the magnetic?

Mr. Grignon: Yes. We use 35mm full-coated magnetic film with three tracks placed upon it for studio operations. This is edited and used as a master for re-recording.

Harry R. Lubcke (Consulting Engineer): You told us about the vertical stereophonic effect and then didn't tell us how you really get that effect; either by an analysis or by reciting the results of tests.

Mr. Grignon: The stereophonic result is due to the following: Somewhere around 500, 800 or 1000 cycles and above, volume differences between microphones are most important. Below these frequencies, phase or time differences are important. Now it is quite easy to see that an infinite variety of combinations of phase relations, intensity differences and ratio of direct-to-reverberant sound arises. Manifestly, no two pick-up circumstances can be quite alike, so placement in any situations nearly alike will be determined by the amounts by which the various factors differ.

Mr. Lubcke: Suppose you move the person or sound source up and down, how does that affect the line of microphone?

Mr. Grignon: You might put the sound source on the periphery of a vertical wheel pivoted about the center microphone and then it can be argued that the pick-up conditions do not change no matter where the sound source is on the wheel. This is not quite correct, although in some instances no vertical placement difference could be detected. The phase differences and intensity differences certainly are constant in the assumed case, but the relative ratio of direct-to-reverberant sounds can and will vary, and if the sound source itself has directivity, such as a human being has, then the intensity differences can also be affected by the direction in which the sound is emitted. Finally, the placement can sometimes be exaggerated by the method of pick-up. I think Dr. Fletcher has something to say that will clarify this.

Dr. Harvey Fletcher (*Brigham Young Univ., Provo, Utah*): I made the statement that you need nine microphones to get the same fidelity up and down and sidewise as you do for three when the motion is only sidewise. However, with three microphones it's obvious that you can get up and down and also sidewise motion, but the quality of the reproduction will only be equivalent to that obtained with two microphones on the horizontal stage.

Mr. Grignon: You will observe in the forthcoming demonstration an airplane that takes off from La Guardia Field, starts about screen center and goes up to the upper lefthand corner of the screen and keeps on going out. Look for that one and you will see that it does go out. We have many opaques where a seated actor stands up and speaks the dialogue and when he stands up he goes out of screen and so his voice comes from above screen. You have to experience these things to believe them, but they do happen.

Richard H. Ranger (*Rangertone, Inc., Newark, N.J.*): I want to thank Mr. Grignon and Dr. Fletcher for giving us such a good start in this stereophonic work, but I would like to give a few observations that I have made. Mr. Grignon, you said that you do not want to fade out any of the microphones; you want to have all three on all the time.

Mr. Grignon: That's correct.

Col. Ranger: Isn't it more directly correct to say that what you want is to have the three loudspeakers continuously on each sound?

Mr. Grignon: No. It isn't. If you cut out any one microphone circuit you have a two-channel system instead of a three-channel system, and the quality will suffer.

Col. Ranger: Well, it seems we have a little chance for an argument here.

Mr. Grignon: We do have. But this can be proved.

Col. Ranger: Well, I've been doing it too. The point in true stereophonic work, as I understand it, is that what you are doing is to give the audience an apparent location of the sound by the direction and intensity of what it receives regardless of the means by which this is accomplished. Two loudspeakers supplied by a differential sound can only indicate the possible source of their combined sound along a hyperbola. Adding another loudspeaker gives another hyperbola line, and the intersections of these two hyperbolas will give more than one apparent source, so that all that they can do is to give a vague sense of the apparent location.

Now when you move the microphones around during the shooting, you certainly are playing havoc with these hyperbolas that have to give the location sense on playback.

I agree that stereophonic sound can give you something that you cannot get in any other way; but unless it is very carefully handled it can give some things that you do not want, such as extra reverberation and indefiniteness. We are very fortunate in that we are tying our new stereophonic sound to the expanded pictures where the audience will naturally expect sound to come from the wider angle. Motion-pic-

ture techniques have always been geared to make the audience think they see and hear what the director wanted them to. And this new stereophonic sound can help in this if it is arranged so as to give the audience the proper effect, whether it is produced from one or any number of microphones and speakers.

W. R. Holm (*E. I. du Pont*): The microphone techniques which you explained — are they vastly different for Cinerama or CinemaScope and for true 3-D, or are they somewhat the same?

Mr. Grignon: I cannot say anything regarding Cinerama, except that I know they use more channels than we do. As far as CinemaScope is concerned, this is exactly what we are doing. This is a technique that we developed eight years ago and are using today in the production of motion pictures.

Dr. Fletcher: I just wanted to answer Col. Ranger's statement by saying that Dr. J. C. Steinberg made tests to see how near the apparent position of the source was to that of the actual position when the recording was made. The results are given in the symposium of papers published in the *Journal* in October 1941. Of course, there's not a one-to-one correspondence, but it's pretty good.

J. Roy Rogaway (*Student, USC*): You mentioned that the placement of the speaker would be at about a third of the screen width. In the Warner Bros. process they seem to place the speaker all round the theater. Would you briefly discuss the advantages and disadvantages as far as realism is concerned?

Mr. Grignon: The Warner Bros. situation is a little bit different. For one thing, I think we need wider pictures to do a good job with stereophonic. They are doing what they best can do at the moment, with what material they have. The surround speakers are another matter. [They are not connected in any way with true stereophonic reproduction from the screen, but are purely devices intended to produce a psychological effect.]

Loudspeakers and Amplifiers for Use With Stereophonic Reproduction in the Theater

By JOHN K. HILLIARD

Microphones, loudspeakers and amplifiers now being installed for stereophonic reproduction of motion pictures in theaters are described. Detailed characteristics of the individual components are analyzed, along with methods of providing proper equalization. Typical installation methods are also outlined.

Many persons attending the Spring 1953 Convention of the Society heard demonstrations of practical theater stereophonic sound for the first time. The Program Committee wisely included visits to Cinerama, demonstrations of CinemaScope, and other methods in the formal program of the Convention; and three-dimensional color with WarnerPhonic sound is currently being shown to the public.

The Paramount, New York, was probably the first theater which for normal operation used a stereophonic system. This theater is using 75 w of audio power on each of the three stage loudspeakers, and 150 w from the regular theater sound system is available for the auditorium loudspeakers. It has been found necessary for the three amplifier systems and three loudspeaker systems which operate from the stage area to be absolutely identical. The Paramount, New York, has 256-type power amplifiers and A-2 loudspeaker systems.

The Roxy Theatre, Loew's State, Loew's Capitol and other Broadway, New York, theaters are now being equipped with 75-w amplifiers and A-2 loudspeaker systems.

The Paramount Hollywood is an identical installation with the exception of the use of a Westrex magnetic reproducer in the Paramount Hollywood, and an RCA magnetic reproducer in the Paramount Downtown, Los Angeles. In the West Coast Theatre, Long Beach, A-4 loudspeaker systems are used in connection with Simplex, 60-w amplifier systems and a Stancil-Hoffman reproducer. For the CinemaScope demonstration on the Fox Western Avenue lot, Altec A-1 loudspeaker systems driven by 75-w amplifier channels provide the sound source. In the various review rooms where demonstration films are now in progress, it has been customary to use A-4 loudspeaker

Presented on May 1, 1953, at the Society's Convention at Los Angeles by John K. Hilliard, Altec Lansing Corp., 2237 Mandeville Canyon Rd., Los Angeles 49. (This paper was received on June 1, 1953.)

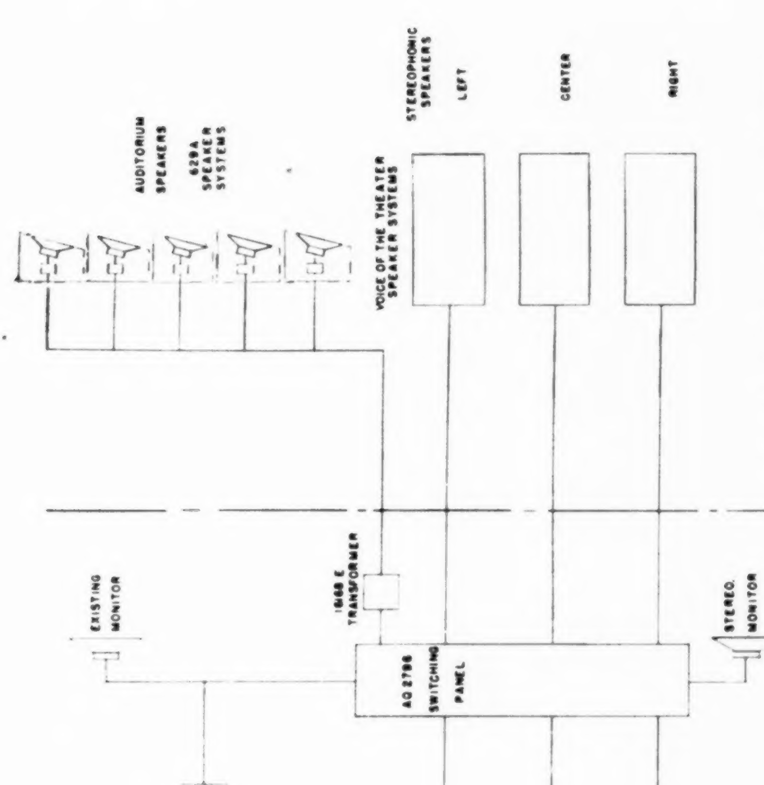

Fig. 1. Typical stereophonic sound system.

systems for the smaller rooms and the A-2 loudspeaker systems for the larger rooms. The equipment details of the installations which have been mentioned are typical of approximately 30 installations in various parts of the country for public showings of Warner's *House of Wax* and other stereophonic pictures which are shortly to be released, as well as for limited demonstrations of CinemaScope.

In planning installations, it has been found absolutely necessary that the three stage loudspeakers be identical in size and type. When these loudspeakers are merely similar rather than identical, the true stereophonic effect is not obtained and dialogue or sound effects tend to jump from location to location in disconcerting discontinuity. It is also believed that it is necessary for the three stereophonic amplifier systems to be identical, since very curious effects have been observed where efforts have been made to use amplifiers which may appear to be similar but which are not identical.

It may be that future experience will determine that some latitude exists in this matter, but our knowledge to date causes us to stress the belief that the use of identical equipment and very careful matching adjustments between the three channels of the stereophonic systems are essential.

Description of Apparatus

Figure 1 is a block schematic of the essential elements for the reproduction of three-channel, stereophonic sound. Included in this block schematic is the regularly used two-machine booth equipment.

Plans for the showing of such pictures as Warner's *House of Wax*, use the three-channel magnetic stereophonic system for the loudspeakers back of the screen. The righthand, or No. 2, projector photographic track carries the sound effects through the existing amplifier system to the auditorium speakers located on both sides and the rear of the auditorium. The lefthand, or No. 1, projector photographic track carries the normal release sound track and can be used as the primary source of sound through the center speaker if the magnetic system fails.

Currently installed three-channel magnetic machines have low impedance heads. Certain of the studio-type reproducers, such as the RCA, Westrex and Stancil-Hoffman machines, have the associated three preamplifiers as an integral part. Experience to date is not sufficient for a definite recommendation as to the best position of the preamplifiers. In some cases it may be convenient to put them on the front wall or on the main rack with the balance of the stereophonic amplifiers. The Altec A-150-A amplifier used for this purpose has the three magnetic-head preamplifiers, a self-contained power supply and three-step type of gain controls which are ganged together and operated by a single knob.

Figure 2 is a front view of the amplifier with the cover removed. The frequency response of the amplifier determines the entire response of the system and is shown in Fig. 3. The input transformer on each of these preamplifiers has connections so that several impedances, such as 30, 150, 300 and 600 ohm are available.

The gain controls are 100,000-ohm, 20-step, 2-db/step potentiometers inserted between the third stage and the cathode follower. The output of each preamplifier is connected to its respective power amplifier. The Altec 1500-series amplifiers are provided for this purpose. The 1530A amplifier is shown in Fig. 4. It has a gain of 75 db with a frequency response of ± 1 db over the range of 20 cycles/sec to 20 kc. The power output is a nominal 70 w and the power curve is shown in Fig. 5. The output noise level is -43 dbm. Load impedances of 4, 8 and 16 ohm, and a 70-v line

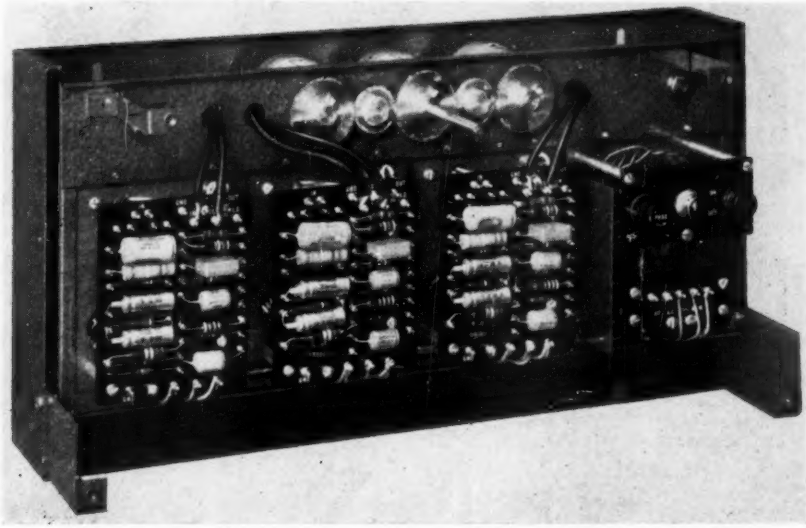

Fig. 2. Altec A-150-A three-channel amplifier, with cover removed.

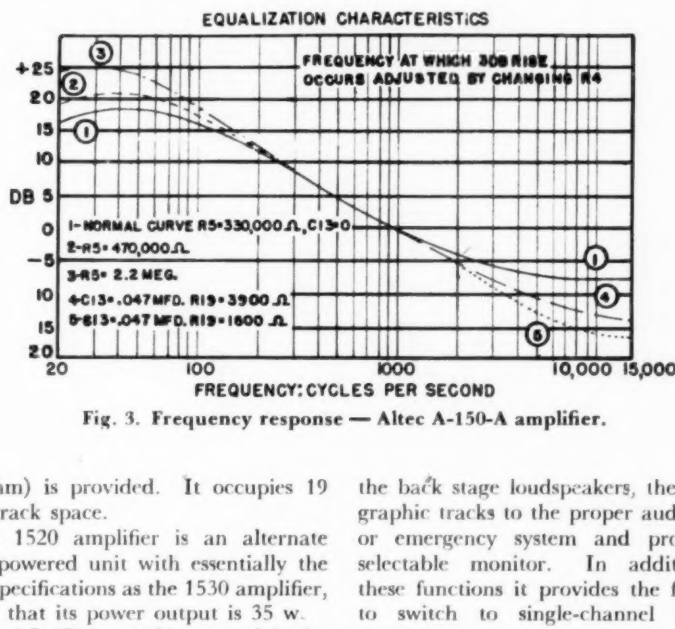

Fig. 3. Frequency response — Altec A-150-A amplifier.

(70 ohm) is provided. It occupies 19 in. of rack space.

The 1520 amplifier is an alternate lower-powered unit with essentially the same specifications as the 1530 amplifier, except that its power output is 35 w.

The AQ-2796 switching panel is designed to distribute the output of the three-channel, magnetic amplifiers to the back stage loudspeakers, the photographic tracks to the proper auditorium or emergency system and provide a selectable monitor. In addition to these functions it provides the facilities to switch to single-channel or flat operation.

The output of the three-channel magnetic track is fed through the output

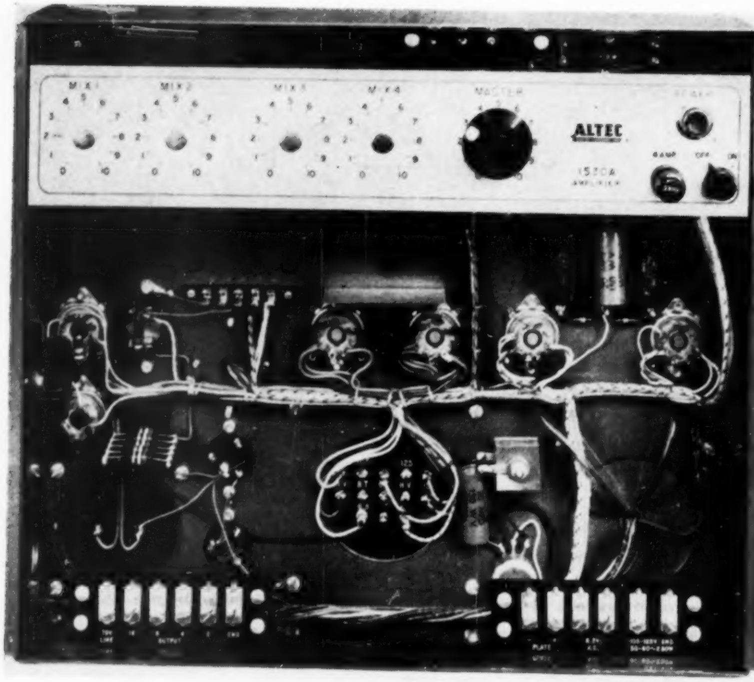

Fig. 4. Altec 1530A amplifier.

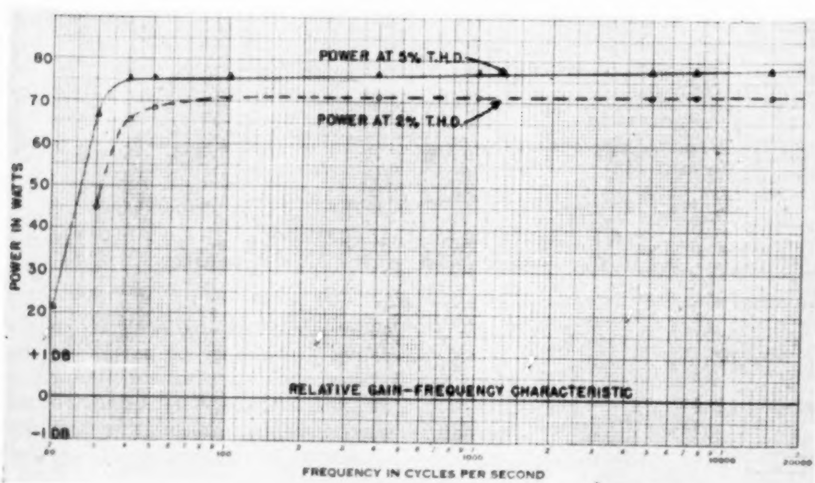

Fig. 5. Altec 1530A amplifier, 16 ohm load — 16 ohm tap, typical response with random tube selection.

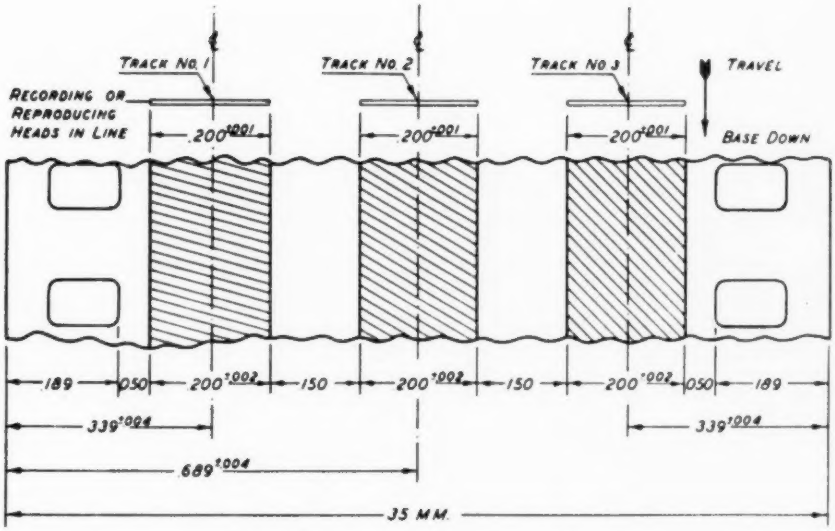

Fig. 6. Track dimensions and positions.

panel to the righthand, center and lefthand loudspeaker systems back of the screen.

Present Motion Picture Research Council standards specify the relative track vs. speaker locations as follows: The No. 1 track is designated as that which feeds the audience left speaker. The No. 2 track feeds the center speaker and the No. 3 track, the audience right speaker. On the reproducer, the No. 1 reproducer head is away from the operator (Fig. 6).

Motor Systems

Due to the shortage of motor systems, several types of interlock and synchronous motors are used. The motor system which appears to have the best possibility of standardization is the two-pole, single-phase motor. This motor is coupled to the standard projection-machine induction motor by a timing belt or chain, with a pulley ratio of 49:40. The two-pole motor is thus driven at an approximate speed of 1440 rpm. This "piggyback" method allows the projector to be interlocked with the other projectors and the three-channel magnetic machine, by tying all of the rotors together. The projector can be started and operated separately with the induction motor or it can be thrown to interlock position, so as to be driven in step with the other machines.

The use of single-phase excitation for the interlock is practical because of the large difference in its normal speed of 3600 rpm and its driven speed of 1440 rpm. Conventional interlock equipment in the past has used four-pole motors and it was necessary to use three-phase to prevent runaway. This difference between normal and driven speed is the ratio of 1800 rpm to 1440 rpm. Also the two-pole motor enables the operator to frame up the motor and shutter on a no-error basis.

Figure 7 shows the Altec A-2 loudspeaker system which is normally supplied for theaters having more than 1600 seats. For theaters having less than 1600 seats and studio review rooms, the

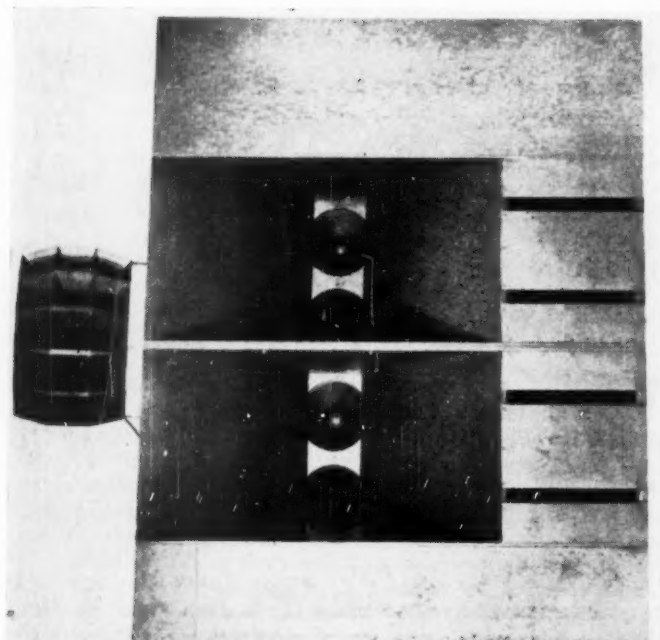

Fig. 7. Altec A-2 loudspeaker.

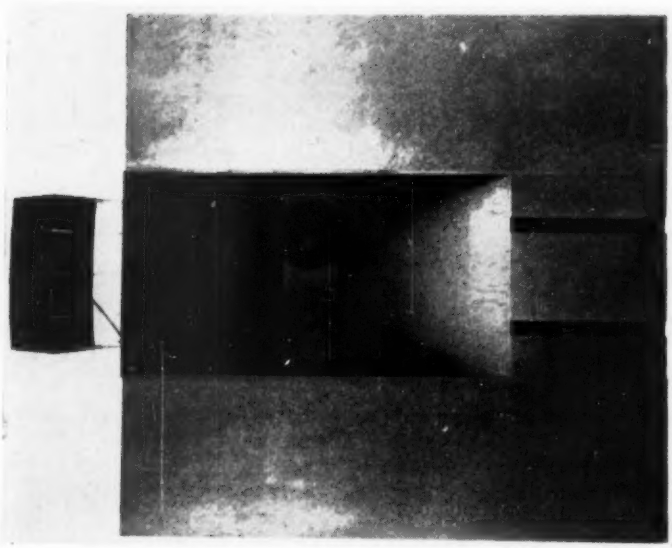

Fig. 8. Altec A-4 loudspeaker.

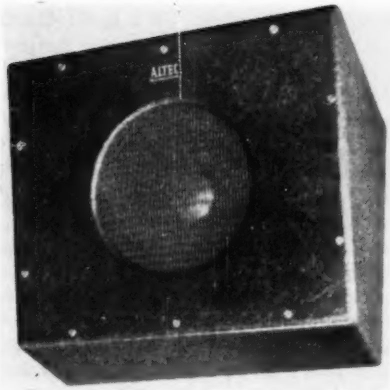

Fig. 9. Altec 629-type auditorium loudspeaker.

A-4 system is used (Fig. 8). Figure 9 shows a typical auditorium speaker. As many as 26 of these 629-type loudspeakers are used in the larger theaters and in the smaller theaters approximately 15 units are provided.

Cinerama Installations

Present Cinerama sound systems use five A-2 loudspeaker systems back of the screen and eight two-way loudspeakers in the auditorium. A seven-channel magnetic track is employed with five channels for the auditorium speakers.

The loudspeakers back of the screen are symmetrically placed with the outside speakers being near the edge of the screen (see Fig. 10). Two multicellular, high-frequency horns are used with each loudspeaker system. The necks of the high-frequency horns are crossed so that the peripheral contour of the two horns is continuous and will give 180° distribution, and can thus cover the entire audience area. Each one of these speaker systems is powered with an Altec 75-w amplifier. The

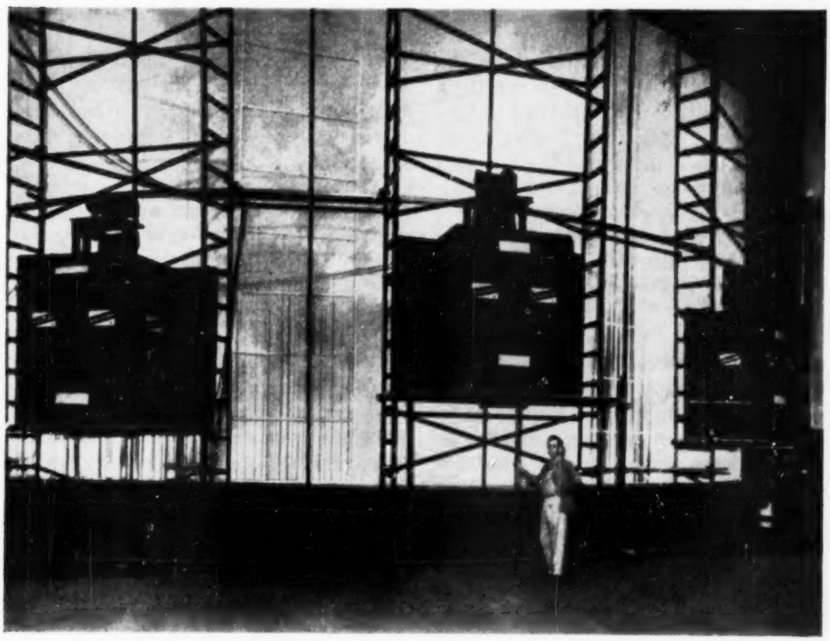

Fig. 10. Arrangement of loudspeakers behind screen.

signal-to-noise ratio in this overall system is approximately 58 db, the limiting factor being the residual background noise of the tape. The amplifier signal-to-noise is maintained at 63 db. The use of auditorium speakers in general requires that the signal-to-noise ratio be improved over that necessary for stage speakers only. The auditorium speakers are located relatively close to some portions of the audience and a high signal-to-noise ratio must be maintained, so that this noise will not mask the sound coming from the backstage speakers or be audible during the long intervals in which no signal is coming from the auditorium speakers.

Originally it was considered necessary to mute the auditorium speakers during intervals of no signal, but it was found that when adequate signal-to-noise ratio was maintained, this function was not necessary.

70-v Distribution System

It was mentioned earlier that a 70-v tap was supplied on the output of the power amplifiers. This 70-v system is comparatively new in theater sound engineering. Negative feedback on power amplifiers provides a low internal-output impedance and its use approximates a constant-voltage output source.

When we refer to a 70-v or constant-voltage distribution line, it is not meant that the voltage on this line is always 70 v., any more than we mean that the power drawn from a 70-w power amplifier is always 70 w. The 70 v is the maximum voltage on peaks at the output of the amplifier. Acceptance of this standardized voltage means that the rated load impedance of amplifiers of different power capacity has been chosen so that the voltage peak is the same for a low-powered amplifier as for a high-powered amplifier. For example, to produce 70 v at rated power on a 70-w amplifier requires that the load impedance be 70 ohm. In the case of a 35-w amplifier, the load impedance should be 140 ohm. In a loudspeaker distribution circuit such as used for the auditorium speakers, each loudspeaker will have an associated transformer which permits the impedance at this point to be adjusted to a value proper for use with the 70-v system. Thus, if an individual loudspeaker requires 5 w, the 5-w transformer tap is used, which makes its impedance such that it will draw 5 w of power when connected to the 70-v output of either a 70-w amplifier or 35-w amplifier. The same loudspeaker can be arranged to take lower or higher power by the use of a different tap on the transformer.

In practice the connection of a number of loudspeakers becomes very simple. First, the power needed for each loudspeaker location is determined and the transformer tap is chosen which will give this power on the 70-v circuit. The power required for all the loudspeakers is added up and an amplifier chosen which is capable of supplying at least this amount of power. All loudspeaker transformer inputs may then be connected in parallel to the 70-v output of the amplifier without any further consideration of impedance relations.

The use of the 70-v or constant-voltage distribution system provides a high degree of flexibility in adjusting the power to each speaker. Within its capabilities, the constant-voltage distribution system is very similar to the concept of a 110-v system as employed in our conventional 60-cycle distribution for domestic power. The voltage remains constant until the output of the generator is exceeded, and at that point, the system is overloaded. Another advantage is that the current in the distribution line is lower than with the conventional impedances used on loudspeakers such as 16 ohm or lower. This permits the use of smaller-sized conductors and allows them to be placed along the walls of the auditorium in an exposed manner if necessary.

There are many suggested magnetic and photographic sound-track combinations that may be used with the various types of picture presentation.

At this time, however, it appears that any and all of these pictures will require a minimum of three-channel stereo sound. The equipment recommended thus becomes a basic part of all systems.

Discussion

Arthur C. Blaney (RCA Victor Div., Hollywood, Calif.): In dealing with a number of these installations have you encountered a lot of hum problems — the usual thing you would expect in magnetic reproducing systems?

Mr. Hilliard: I certainly think that everyone has had trouble with them, but they have been able to work on them within established limits. We will always go through a period at the beginning similar to the rush that we are in now. Many small troubles will annoy us at the time of installation; but after a few of these installations are over, the problems will be greatly reduced, since there are no basic difficulties in design.

V. Kramer (Universal-International Pictures): Did you say that No. 1 Channel is always away from the operator?

Mr. Hilliard: That's the way it has been designated.

Mr. Kramer: On some of these reproducers where the magnetic heads are on the outside of the drum, wouldn't that put the track towards the operator? Are the emulsions wound out or wound in on the reel?

Mr. Hilliard: I don't know about that. The reason I mentioned it was so that those people who are not aware of the Research Council recommendation could investigate it and if they wish, could conform with that practice.

Dr. J. G. Frayne (Westrex Corps): Two different practices are followed with respect to emulsion position. In converted theater-type dummies the coating is on the outside of the reel and the No. 1 track is then furthest from the operator. In the case of cabinet-type three-track reproducers the emulsion is generally wound inside. In this case the No. 1 track is nearest the operator.

John Volkmann (RCA Victor Div., Camden, N.J.): With regard to the surround speakers in the case of the Warnerphonic system what spacing are you using between the centers of the loudspeakers?

Mr. Hilliard: That must, of necessity, vary with the geometry of the house, and I'm quite sure that the practice is to try to space them as uniformly as possible insofar as the seating arrangement is concerned. As I indicated, the smaller houses have 15 and I believe the Roxy now has as many as 33 or 35 to get uniformity of loudness without having the sound exaggerated in any one particular position.

Mr. Volkmann: It might be of interest to the group here to know what rule has been followed in RCA stereophonic installations; namely determine the average height of balcony ledge above the floor, multiply it by two, and that should be approximately the spacing between the direct-radiator surround speakers. This rule is for loudspeakers which have a distribution factor not less than 60°. In general, direct-radiator loudspeakers have varying distribution characteristics in the range of 60 to 90°. In the balcony the same spacing is used and the axes of the loudspeakers in general are directed so as to cover appoximately half the distance across the room.

Dr. Frayne: In Mr. Hilliard's very excellent presentation he spoke of true stereophonic sound. I wonder if he would like to define what is meant by true stereophonic sound.

Mr. Hilliard: I do not have any simple answer to that question. I think we will all have to struggle through this thing until we finally find an ultimate position which gives good stereophonic reproduction.

Multiple-Track Magnetic Heads

By KURT SINGER and MICHAEL RETTINGER

The object of this investigation was to devise an economical construction method for multiple-track magnetic heads used in recording on 35mm perforated magnetic film, particularly when such (reproducing) devices are used in a theater for the stereophonic presentation of motion pictures. Two methods of construction were employed. The head built by one method shows somewhat more crosstalk reduction, but the head built by the other method is less expensive to manufacture and also shows a number of other superior features. Both magnetic heads are entirely satisfactory for the purpose intended, in regard to frequency response as well as to sensitivity and crosstalk.

With the advent of Cinerama, increased attention is again being directed to the recording and reproducing of stereophonic sound in motion pictures. It may be remembered that in 1940 the Walt Disney production *Fantasia* was reproduced stereophonically with the use of three photographic sound tracks and one photographic control track with three frequencies. Since magnetic recording has, to a large extent, replaced photographic recording in motion-picture studios, it stands to reason that future stereophonic recordings, just as was done for Cinerama, will be made with magnetic film.

Two six-track heads were constructed for the purpose of obtaining data for multichannel magnetic recordings on 35mm magnetic film. Subsequently, such a unit will be referred to as a cluster, to distinguish it from the six individual heads of which a cluster is composed. Two methods of construction were employed: one cluster was built by assembling six individual heads in their proper shield cans; the other unit, by combining two half clusters, which will be described in greater detail later.

The width of each track was 0.080 in. The space between the tracks was 0.084 in. Each outside track was 0.050 in. from the closest sprocket-hole edge. The heads were numbered 1, 2, 3, 4, 5 and 6, number 6 being closest to the recorder panel.

Assembling six individual heads in their proper shield cans presented numerous difficulties, not only in respect to the construction of the individual heads, which had to be made small enough to allow some space between the heads for individual azimuth adjustment, but also assembly-wise. Each head had to be adjusted for track placement, head height, bearing, azimuth and rotation (to bring the six gaps into one line).

Presented on May 1, 1953, at the Society's Convention at Los Angeles, by Kurt Singer and Michael Rettinger, Radio Corporation of America, RCA Victor Div., 1560 N. Vine St., Hollywood 28, Calif.
(This paper was received April 22, 1953.)

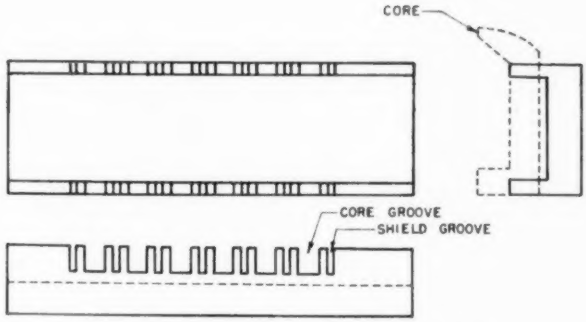

Fig. 1. Brass rack used in No. 2 cluster.

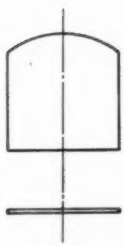

Fig. 2. Mu-metal partition used in No. 2 cluster.

All adjustments were made under a microscope, utilizing special tools and assembly fixtures. The cluster was then plasticized in a rectangular aluminum receptacle.

Assembling the cluster composed of two half clusters was easier and quicker and could be performed with greater accuracy in every respect. Six half cores, wound with a predetermined number of turns of wire, were put in a brass rack, into which grooves had been milled for the placement of the cores. Additional grooves had been provided in the rack between the core grooves for the location of mu-metal partitions required for shielding purposes. After adjusting core positions under a microscope for accurate track placement with a special assembly fixture, the mu-metal partitions were inserted in their grooves, the cluster was filled with casting resin and placed in an oven for curing. Before the half cluster was completely polymerized, the greased, 0.02 in. thick mu-metal partitions, which were twice the size of the cores (see Figs. 1 and 2), were pulled out of the rack, after which the half cluster was allowed to cure for the required period. This was done to permit the lapping of each half cluster on a flat plate; otherwise, with the partitions protruding, this lapping would not have been possible. What was desired above all, was that all the pole faces should be in the same plane. The partitions had to be inserted to produce grooves in the plastic, and they could be removed only while the plastic was hot and incompletely polymerized. After soldering the coil ends to a small terminal board fixed to the brass rack, equipping the cores with the required front- and back-gap spacers, and reinserting the mu-metal partitions, the two half clusters were screwed together, after which the cluster was plasticized in the same type of receptacle in which the cluster had been plasticized which consisted of six individual heads.

Subsequently the cluster made by assembling six individual heads will be referred to as cluster No. 1, and the cluster built by combining two half clusters, as cluster No. 2.

Fig. 3. A head used in construction of No. 1 cluster.

Fig. 4. Receptacle used for each of the clusters.

It may be noted that the azimuth of each head of cluster No. 2 can be set, under a microscope, 11 times more accurately than the azimuth of any of the six heads of cluster No. 1. The reason for this is that the combined gap length of the heads of cluster No. 2, counting also the interstices between the tracks, is 11 times the gap length of an individual head. Thus, the combined gap length of the heads of cluster No. 2 can be utilized for the azimuth setting of any one head, because all the pole faces are in the same plane as noted before. The inductances of each of the heads varied slightly about a nominal value of 5 mh.

The operational tests for both clusters consisted of the following:

Determination of maximum sensitivity bias. Approximately 10-ma bias per head was required for each cluster. This test was made at a frequency of 400 cycles at a level 20 db below the nominal 100% modulation level.

Determination of 100% modulation level at 10-ma bias. A 400-cycle signal of a level of +1 dbm can be applied to the record head to obtain playback-head output with a distortion content of 2.5%.

Frequency characteristic. The frequency characteristic was determined at a recording level of 10 db below 100% modulation. We made use of our standard pre- and post-equalization frequency characteristics as currently employed in our PM-63 racks. Measurements were made by recording on cluster No. 1 and reproducing first on cluster No. 2 and then on cluster No. 1 itself. The difference in the frequency characteristics thus obtained can be ascribed to difference in slit azimuth between cluster No. 1 and cluster No. 2. In general the frequency characteristics of both cluster No. 1 and No. 2 were well within the limits set up for our standard magnetic heads used for single- and triple-track recording.

Determination of slit azimuth differences between the six heads in cluster No. 1. This measurement was made by making frequency recordings with cluster No. 1 as recording head. The recordings were then reproduced first on cluster No. 2 and then on cluster No. 1. Since cluster No. 2 was constructed in such a manner that the azimuth deviation of all its component heads was the same as explained in detail in the first part of this engineering memorandum, the difference in high-frequency output experienced between using cluster No. 2 and cluster No. 1 as reproducing heads, represents the azimuth difference of the individual heads of cluster No. 1. The table below indicates the improvements in 10,000-cycle response that were obtained when playing back the recordings made on cluster No. 1 on itself, as compared to playback on cluster No. 2.

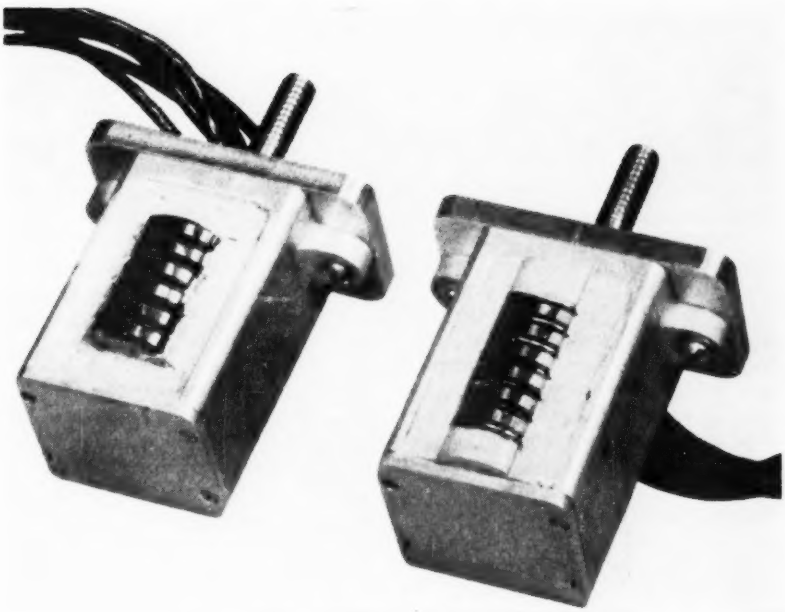

Fig. 5. Clusters Nos. 1 and 2 (left to right).

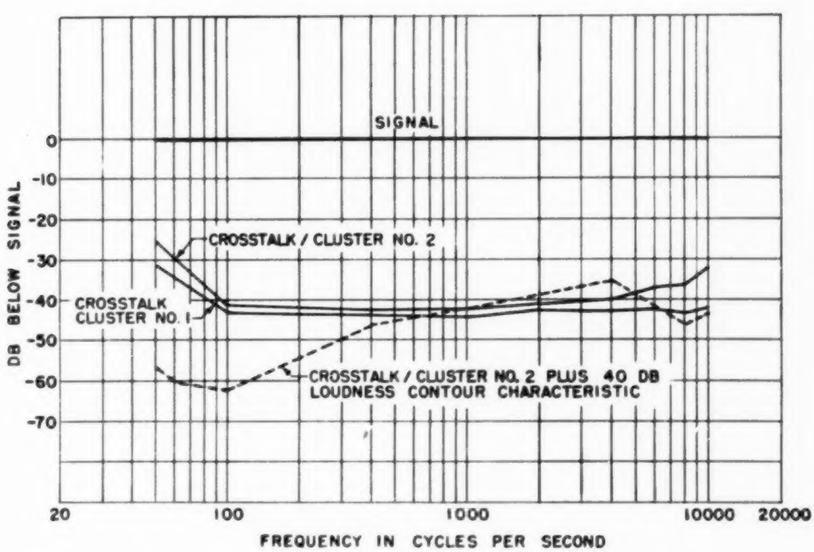

Fig. 6. Signal-to-crosstalk ratio between adjacent heads.

	Magnetic Head Number					
	1	2	3	4	5	6
10,000-cycle response improvement due to perfect azimuth	+0.9 db	+1 db	+0.5 db	+0.1 db	+0.8 db	+1.6 db

Crosstalk of adjacent heads. The curve shown in Fig. 6, depicts the signal-to-crosstalk ratio between adjacent heads. This measurement was made by recording frequencies at a level 10 db below 100% modulation on head No. 3 of cluster No. 1 and No. 2. While recording on head No. 3, normal recording bias without signal was applied to the adjacent heads No. 2 and No. 4. Subsequently, heads Nos. 2, 3 and 4 were used as reproducing heads and the output levels obtained from the three adjacent tracks were noted. In Fig. 6, the line marked "Signal" indicates the output from the track on which the various frequencies had been recorded. Below the signal reference line, two curves are shown which indicate the outputs that had been obtained when playing back the tracks adjacent to the originally recorded track. It can be seen that the crosstalk from cluster No. 2 is somewhat higher than the crosstalk from cluster No. 1, particularly at the high and low frequencies.

Shown also in the figure is the curve obtained when the 40-db equal-loudness contour characteristic is superimposed on the crosstalk curve for cluster No. 2. This curve shows that both the extreme lows and extreme highs are not audible when the crosstalk from cluster No. 2 is reproduced at such a level that its 1000-cycle component is 40 db above threshold.

Determination of signal-to-noise ratio. A signal-to-noise ratio of 57 db, referred to 100% modulation output, was measured. For comparison purposes it should be mentioned that the signal-to-noise ratio on the PM-63 channel with MI-10795-1 magnetic heads lies between 55 and 60 db. The crosstalk values shown in Fig. 6 appear more than adequate for motion-picture presentation in auditorium-type theaters. This is based on the well-known findings by W. A. Mueller* who showed that the useful volume range for dialogue in a theater is of the order of of 25 db, and that even for music this range never exceeds 35 db. In the case of review rooms, in which the audience noise is from 30 to 35 db above hearing threshold, compared to 40 to 45 db in auditorium-type theaters, the use of magnetic decouplers may prove desirable.

* W. A. Mueller, "Audience noise as a limitation to the permissible volume range of dialogue in sound motion pictures," *Jour. SMPE, 35:* 48–58, July 1940.

Stereophonic Recording and Reproducing Equipment

By J. G. FRAYNE and E. W. TEMPLIN

This paper describes new stereophonic recording channel equipment including a six-position mixer and portable three-channel recorder. For re-recording, the previously described triple-track recorder-reproducer is available. For review-room and theater reproduction, a theater-type dummy equipped for three-channel stereophonic reproduction is described.

When three-channel stereophonic film recording was first demonstrated to the industry by Fletcher[1] the medium used was photographic film, the recording information being contained in three 80-mil variable-area bi-lateral tracks and a control track. In order to arrive at a satisfactory signal-to-noise ratio for this improved type of recording, rather complex recording and reproducing transmission circuits requiring the use of a compressor in recording and an expander in reproduction were employed. Unfortunately, the system demonstrated by Fletcher never got beyond the experimental stage due in part to its complexity, but mainly due to the apathy of the motion-picture industry at that time to changing over to a new medium of sound presentation in theaters. The widespread use of magnetic recording at the present time makes possible the recording of three or more stereophonic channels on a single 35mm film with a volume range comparable to that obtained by Fletcher and without the use of the compandor type of transmission circuit. Fortunately, a studio-type triple-track magnetic recorder designed for recording and reproducing three different intelligences had already been developed[2] and was immediately available for the present stereophonic program.

The basic items required for a complete stereophonic recording program include three-channel (a) portable recording equipment, (b) reviewing facilities, (c) re-recording facilities and (d) theater-type projection equipment. In addition a re-recording console equipped for three-channel stereophonic must be available. In this paper we are describing the basic elements presently being made available for stereophonic recording by the Westrex Corp.

Presented on May 1, 1953, at the Society's Convention at Los Angeles by John G. Frayne and E. W. Templin (who read the paper), Westrex Corp., 6601 Romaine St., Hollywood 38, Calif.
(This paper was received on May 13, 1953.)

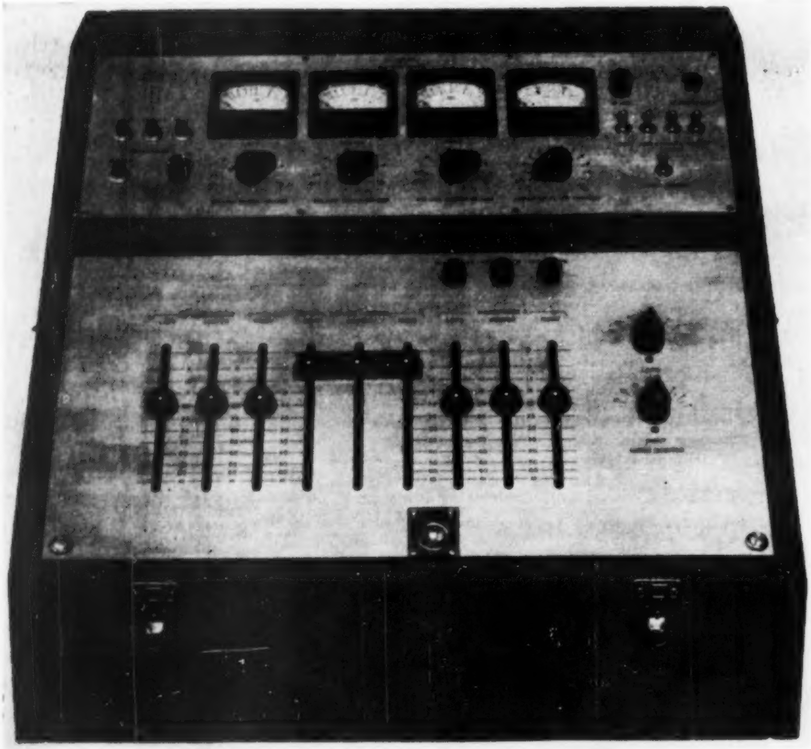

Fig. 1. Westrex RA-1518 Stereophonic Mixer.

Stereophonic Recording Equipment

In order to obtain the type of auditory perspective envisaged by Fletcher, it is necessary that the original pickup on the stage be done by a multiple-channel arrangement, and experience indicates that a minimum of three separate channels, from microphone to loudspeaker, is necessary. In order to meet the requirements of the industry, Westrex has developed within the last few months a complete three-channel stereophonic production recording system consisting of a stereophonic mixer and a stereophonic recorder, with separate power equipment depending on whether a-c or d-c operation is required.

Stereophonic Mixer

We shall first describe the stereophonic mixer which was designed primarily to meet the immediate needs of Twentieth Century-Fox for their stereophonic recordings of CinemaScope. In this case urgent need of the equipment for early production use made it necessary to forego normal considerations of appearance and to provide instead the simplest possible physical design capable of meeting functional and operational needs.

A front view of the mixer is shown in Fig. 1. As seen in the lower panel, linear-type mixing and volume controls are used to permit simultaneous multiple

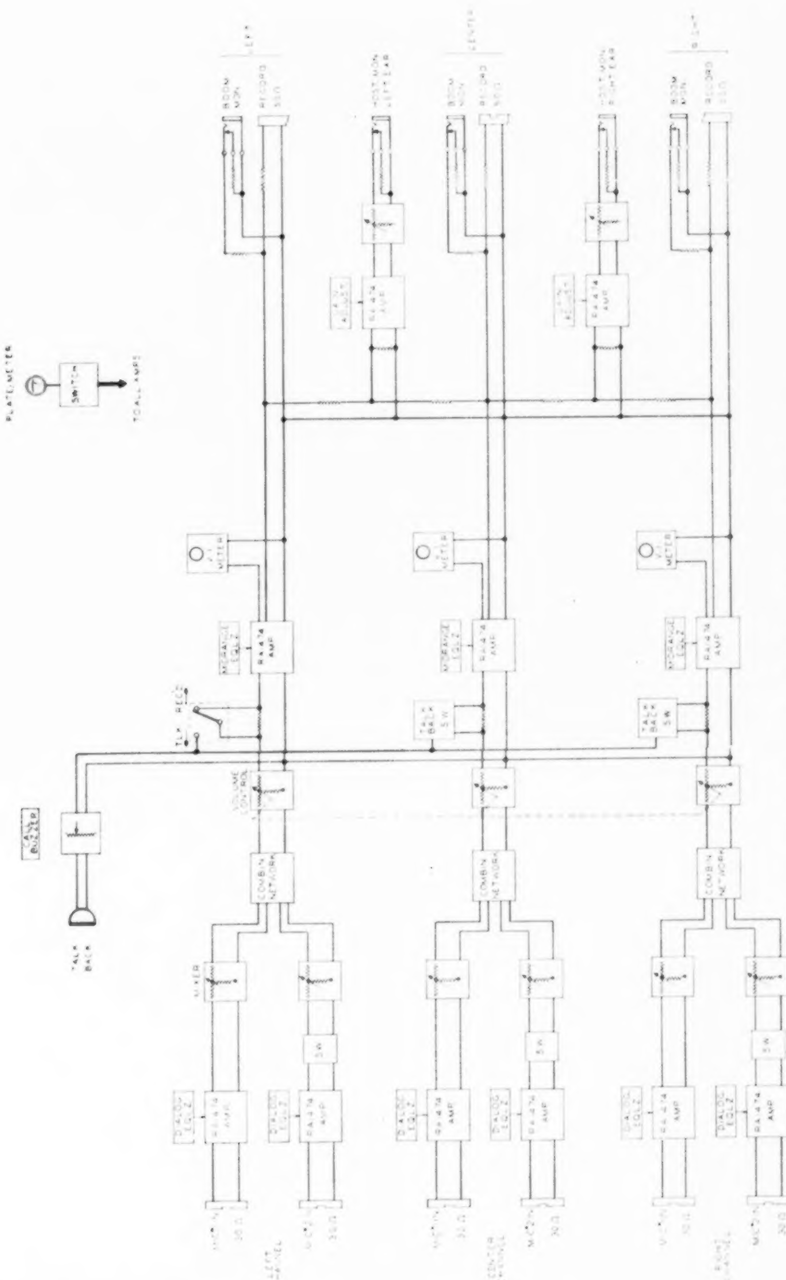

Fig. 2. Block schematic of RA-1518 Stereophonic Mixer.

control by one operator. The group of three mixer controls on the left controls a group of microphones for the left, center and right channels, respectively. The group of three controls on the right controls a second group of microphones. The control bar in the center operates the ganged overall volume controls in the three channels. The two controls on the right are left-ear and right-ear monitor attenuators as described in more detail later.

In the upper panel from left to right are the interphone microphone and push-to-talk switches, the volume indicators for the three channels, a plate-and-heater meter for the amplifiers and the various power switches. The mixer contains all the transmission equipment from microphone input to the magnetic-head circuits as shown in the block schematic, Fig. 2.

Two microphone inputs with separate preamplifiers and mixer controls are provided per channel. A volume control is provided in the common circuit following the individual mixers. The volume controls of the three channels are ganged together to permit common adjustment for all channels. The recording amplifiers following the volume controls provide adequate output level for driving the volume indicators and the recording heads. The volume indicators are connected to the 600-ohm outputs of the recording amplifiers. The recording circuits, however, are taken from 50-ohm taps of the same output transformers. This step-down in impedance decreases the capacity leakage among the three channels in the interconnecting cable and permits separation between mixer and recorder of several hundred feet without objectionable crosstalk.

Boom monitoring is provided separately on each of the three channels at the recording-amplifier output. Binaural headset monitoring is provided with the outputs of the left and center channels combined for the left-ear monitoring and the outputs of the center and right channels combined for the right-ear monitoring. For the same signal level into the mixer-monitor circuits from all three channels, the center channel would have greater subjective loudness because of its presence in both receivers. Proper allowance is made for this in the relative input levels to the left- and right-ear monitoring circuits from the three recording-channel outputs. The signal provided in the left- and right-ear monitoring circuits is obtained by bridging from the recording circuit with approximately 40-db loss. These circuits thus connect the left and center, and the right and center channels together with approximately twice this loss, which is far too low to cause objectionable crosstalk.

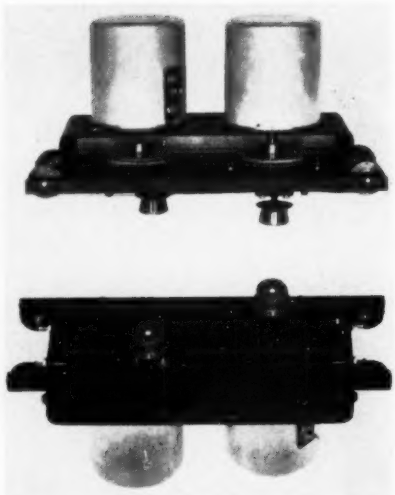

Fig. 3. Attenuator control assembly of RA-1518 Stereophonic Mixer.

Eleven amplifiers are used in the mixer. These are all the general-purpose RA-1474 type which have been previously described.[3] A small plug-in unit connecting to two of the internal high-impedance circuits of the amplifier provides means of inserting

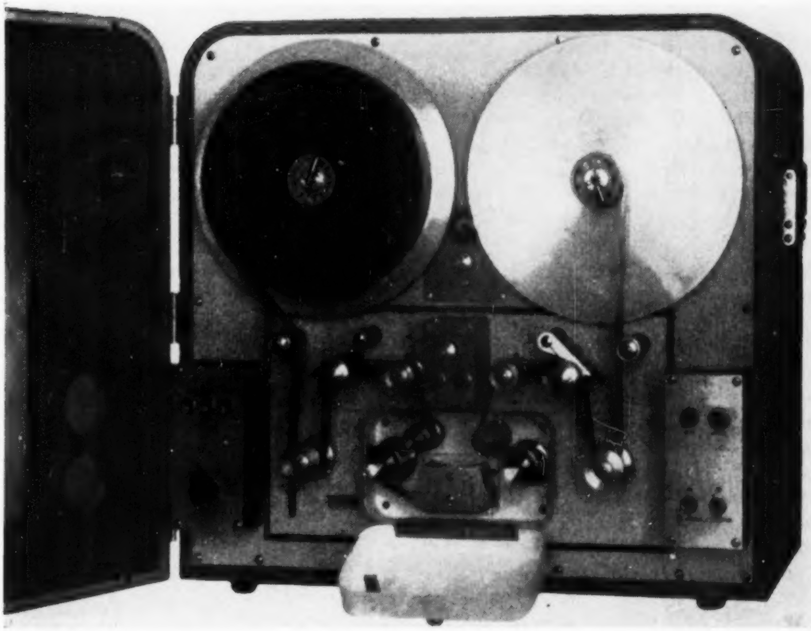

Fig. 4. Westrex RA-1517 Stereophonic Recorder.

equalization and gain control to meet the requirements for the specific applications. In the microphone amplifiers these plug-in units provide adjustable dialogue equalization and the desired low-frequency pre-equalization. In the recording amplifiers they provide adjustable midrange or "presence" equalization, and in the monitoring amplifiers they provide gain control with a flat characteristic. The amplifiers themselves are plug-in units permitting ready replacement or exchange of amplifier positions to expedite localization of troubles.

The requirement for linear motion of the mixer and volume-control drives has been accomplished by the design of the special mixer-control assemblies shown in Fig. 3. Finger-tip touch is all that is required to move the controls. Three mixers can be individually operated by fingers of one hand while the thumb is being used to adjust the volume control. The controls act through a cord-and-pulley drive to operate a conventional continuously wound ladder-type mixer pot. This type of mixer control was first used by Metro-Goldwyn-Mayer in their dubbing-mixer consoles. The schematic shows the other facilities provided in the mixer, including the talk-back microphone with separate press-to-talk switches for each channel, individual current metering for each amplifier and a call buzzer.

Since this first design of a production stereophonic mixer was developed with very little backlog of experience as to the actual production requirements, it was considered wise to err in the direction of providing excess, rather than inadequate, facilities. Undoubtedly, with field experience obtained from the pres-

ent design, considerable reduction in facilities and the overall size and weight of the assembly will be possible.

Although it is expected that occasional travel shots will require switching between microphones in a particular channel, it is now believed that very seldom will it be necessary to provide simultaneous switching of microphones in all three channels during the same take. Consequently, the number of preamplifiers can probably be considerably reduced. It has been suggested that facilities be provided for plugging in an extension accessory-mixer unit to take care of such possibilities. Another alternative would be to provide one extra preamplifier which could be plugged into a second input position of any one of the three channels. Thus, up to half of the preamplifiers and associated mixers could possibly be omitted in the basic mixer. It is also probable that the overall volume control can be eliminated and a three-position 10-db/step gain control, separate in each channel, could be substituted. It also appears that one volume indicator with switching facilities to provide alternate connection to any of the three channels will be adequate. Some studios already feel that binaural headset monitoring for the mixer is unnecessary. This would allow elimination of one of the monitor amplifiers and associated circuit. These possibilities, if realized, will permit reduction of the mixer to a considerably smaller and lighter-weight unit than the model described in this paper.

Stereophonic Recorder

The Westrex RA-1517 Stereophonic Magnetic Recorder uses the basic design of the single-channel Westrex RA-1497 Magnetic Recorder which has come into wide use during the past few years. The change-over from single to triple channel is relatively simple. The single flywheel is replaced with a double-flywheel type of drive similar to that employed in the Westrex RA-1506 triple-track recorder. Figure 4 is a front view of the stereophonic recorder with the sheet-metal cover in the open position. The film path employs the Davis Drive using two impedance drums and their associated flywheels, a tight film loop existing between the two film sprockets. Two sets of triple magnetic heads, one for recording and one for monitoring or reproducing, are located between the impedance drums. Analysis of this type of drive has previously been described in the *Journal*.[2] A bias meter is mounted on the panel between the two film flanges as shown in the photograph and a selector knob is provided for metering the bias current in each individual channel. Three screwdriver-operated controls are supplied for adjusting the bias current in each channel.

The control panel in the lower left corner of the recorder contains three switches permitting monitoring from any one of the three individual tracks or from any combination of tracks. When the motor-drive circuit is open, a relay transfers the monitoring circuits from film monitor to direct monitor from the center recording channel, permitting the recordist to receive instructions from the mixer and to remain in contact with activities on the set during these intervals. The controls directly below the bias-meter panel consist of a transfer switch to set up the circuits for either recording or reproducing and a signal lamp indicating that the circuits are properly connected for these two operations.

The control panel in the lower right corner of the recorder contains a call buzzer, motor "ON" light, power-control switches and talk-back interphone, when used.

Two RA-1508 type triple-track magnetic heads are located between the impedance drums and are enclosed in a box of heavy mu-metal to reduce hum pickup from external sources. The front half of the box is hinged to provide

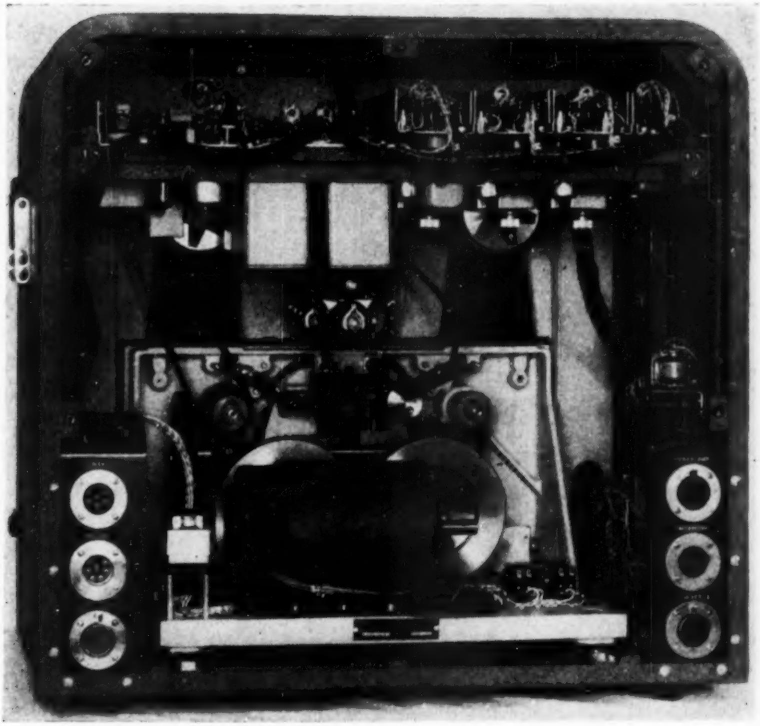

Fig. 5. Westrex RA-1517 Stereophonic Recorder — rear view.

access for threading. One of the triple-track heads is intended primarily for recording and the second primarily for monitoring or reproducing purposes. With this type of head, three 200-mil tracks are laid down in accordance with the proposed ASA Standard for multi-track magnetic operation.

Figure 5 is a rear view of the recorder with the cover removed. The motor and the entire film-drive assembly including the film-reel spindles are mounted on an angle plate which in turn is shock-mounted on slides in the case and is readily removable as a unit. The main drive shaft is coupled to the motor by a synchronous timing belt and sprockets and it in turn drives the film sprockets through steel and nylon gears. This drive system provides quiet operation with very little vibration. The recorder can be operated with synchronous, a-c interlock or multi-duty motors, various motor speeds being accommodated by changing the timing-belt sprockets. The recorder can be operated in a forward or reverse direction. The flutter performance of this recorder is excellent, the total rms flutter being 0.1% or less.

The horizontal equipment frame, located in the upper section of the case, is mounted on rails and is secured by two Camloc wing-head screws. The frame can be pulled out to facilitate the servicing of the electrical units mounted on it. These are, from left to right, the bias oscillator, 60-kc suppression

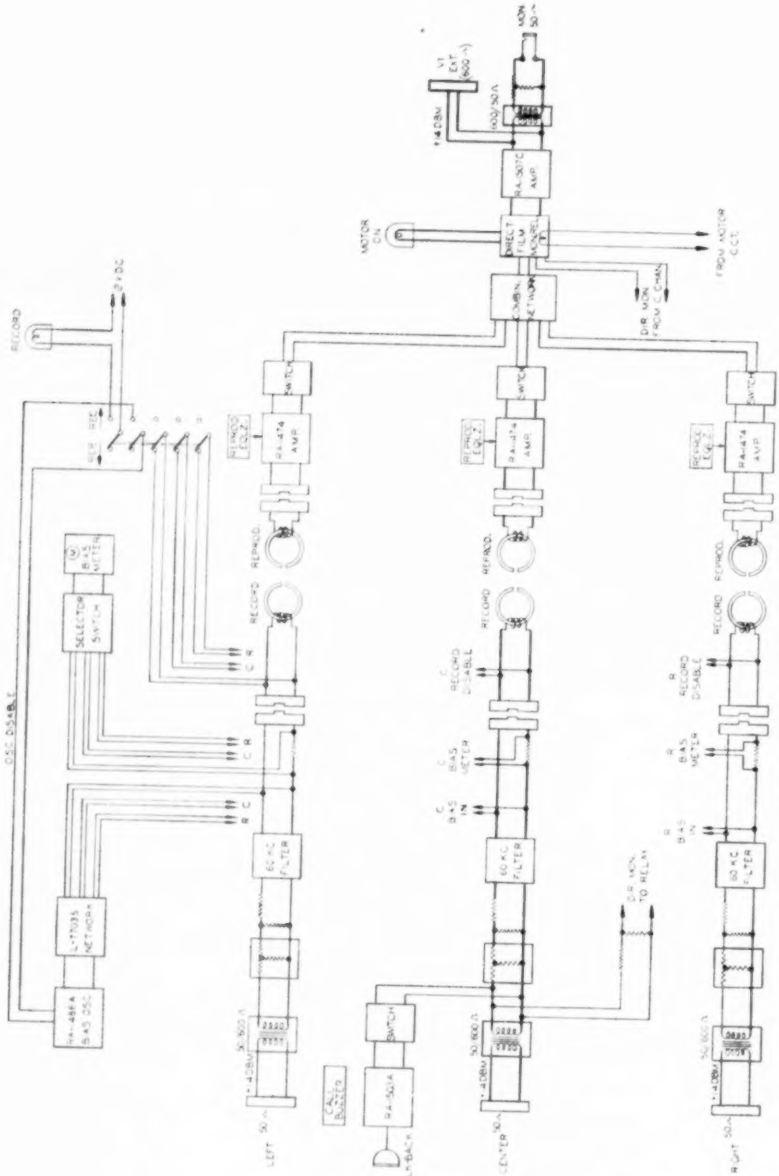

Fig. 6. Block schematic of RA-1517 Stereophonic Recorder.

filters, a bias-distributing network, reproducing amplifiers and monitor-output amplifier, as described in more detail below. Three receptacles accommodate the normal system interconnections. Additional ones, as required, provide for special facilities in particular applications.

Recorder Schematic

A block schematic of the recorder is shown in Fig. 6. The repeat coils at the input of each channel provide impedance match from the 50-ohm line to the 600-ohm recording circuit. These coils would be required even though the lines between mixer and recorder were made at 600 ohm, since they are required to isolate the common direct-monitor circuits at the mixer from the common bias supply to the three channels in the recorder. The 60-kc suppression filters provided in each channel isolate the bias from the volume indicators and recording amplifiers. The bias-distribution network provided between the bias oscillator and the three recording circuits maintains over 60-db isolation between adjacent channels for audio-frequency signals. The recording-and-reproducing triple heads each appear on plugs which may be transposed in the circuit. This flexibility permits emergency use of the reproducing heads for recording and also permits recording and reproducing from the same heads in making azimuth tests or adjustments. The record-reproduce control switch disables the oscillator and shorts the three recording heads under reproducing conditions and operates a warning light under recording conditions.

The preamplifiers in the three reproducing channels are the RA-1474 type previously described, with the plug-in unit in this application containing the 6-db per octave reproducing equalization and low-frequency post-equalization when required. The single-stage RA-1507 Amplifier on the combined output provides monitoring from the film for the recordist at a maximum level equivalent to that of the recording-circuit level input. For those particular studios that wish to make the film monitoring available at the mixer, this permits a quick check between record and reproduce levels for an overall system test. By minor additional wiring the outputs of the three reproducing amplifiers may be extended to permit the recorder to be used as a stereophonic re-recorder, reproducer or playback unit.

Stereophonic Re-recorder

Although the Westrex RA-1506-A triple-track recorder was not originally intended for stereophonic recording, it can be used as a studio stereophonic recorder, re-recorder or reproducer without any change in operation or facilities. This machine, shown in Fig. 7, is capable of operating as a triple-track magnetic recorder from the output of a studio mixing console, and includes the necessary low-end and high-end pre-equalization to permit an essentially flat response from about 50 cycles to 8 kc when the tracks are reproduced over the same type of machine. This recorder-reproducer, which also utilizes the RA-1508 magnetic head, lays down three sound tracks with a crosstalk of approximately −60 db between adjacent tracks at about 1000 cycles. This may be a somewhat greater signal-to-cross-talk ratio than is required for a stereophonic recorder, but such performance permits general multi-track recordings of the highest possible quality and the machine can thus be used interchangeably for either stereophonic or for recording three separate and unrelated signals where crosstalk requirements are very severe.

Stereophonic Sound Reproducer for Theaters

Stereophonic reproduction has not developed to a point where the ultimate disposition of the three tracks for theater presentation can yet be predicted with

any degree of certainty. Obviously the ideal situation would be to associate the three tracks with the picture on a single film. This presents several serious problems which are being actively studied by the industry. In the meanwhile, a separate three-track sound reproducer electrically interlocked with the picture projector will undoubtedly find considerable application.

Westrex has adapted a standard theater-type sound unit for three-track magnetic reproduction. This unit will mount on a standard theater pedestal with a "dummy" head and either standard or large magazines, and operate in electrical interlock with the picture projector. If and when means have been found for combining the sound and picture on one film, the sound head used in this reproducer will undoubtedly be able to accommodate the composite film with a few minor modifications resulting from the final track location and dimension.

Figure 8 shows the operating side of the R8 Reproducer and the associated "dummy" head. As in the stereophonic recorder the tight-loop Davis Drive with two impedance drums is used, the triple magnetic head being located between the drums. If reproduction of standard photographic sound track is also required, the standard impedance drum and optical elements can be retained. The performance of the film-pulling mechanism is quite good, the total flutter being less than 0.1%.

Figure 9 is a view of the drive side of the reproducer. At the left is a single-phase selsyn motor which, together with a similar motor mounted on the picture projector, provides electrical interlock. To its right is the drive motor. This is a 1/6 hp single-phase capacitor-start induction motor. The drive motor and the selsyn motor are coupled together and to the sound-sprocket shaft by two synchronous timing belts and sprockets. For review-room installations where

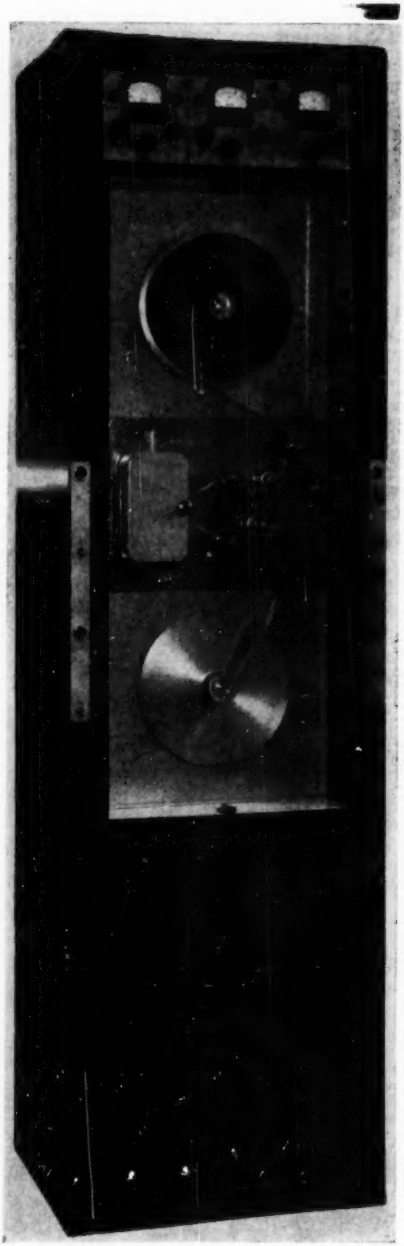

Fig. 7. Westrex RA-1506 Stereophonic Re-recorder.

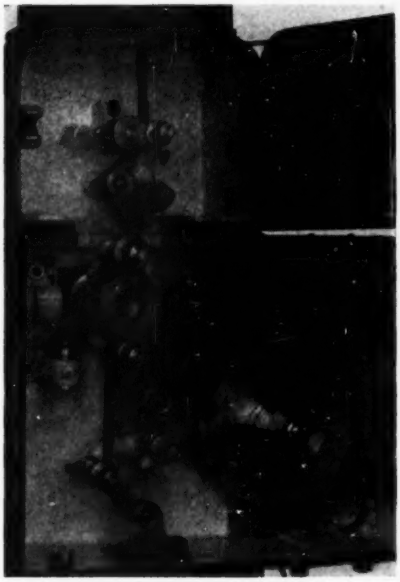

Fig. 8. Westrex R8 Theater Stereophonic Reproducer.

interlock facilities are provided, a standard three-phase interlock motor with a shaft speed of 1200 rpm may be substituted for the two-motor system. The picture shows the "dummy" head as being driven by a silent chain. This chain will be replaced by a synchronous timing belt on production units. The use of timing belts provides quiet operation with negligible vibration.

Figure 10 is a view of two transmission units which are associated with and mounted external to the reproducer. The unit at the right contains the three preamplifiers which accept the outputs of the three magnetic heads and deliver a maximum output level of approximately −15 dbm to the theater system. These amplifiers are identical to the preamplifiers used in the stereophonic recorder and contain the 6-db per octave reproducing-equalization characteristic and whatever low-frequency post-equalization may be required. The unit at the left of the picture delivers line-and-load-regulated plate supply and rectified filament supply for the two T601 Amplifier Assemblies which would normally be supplied in a two-projector system.

Conclusion

With the recording, re-recording and theater reproducing facilities described in this paper, it is now possible for motion-picture studios to initiate a program of stereophonic recording on the stage, carry it through the reviewing and re-recording operations and permit its reproduction in the theater. With the proper use of these facilities, the auditory perspective of the original stage pickup can be preserved in the final reproduction in the theater.

References

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2. C. C. Davis, J. G. Frayne and E. W. Templin, "Multi-channel magnetic recording," *Jour. SMPTE, 58:* 105–118, Feb. 1952.
3. G. R. Crane, J. G. Frayne and E. W. Templin, "Magnetic recording on film," *Jour. SMPTE, 56:* 295–309, Mar. 1951.

Discussion

E. W. D'Arcy (De Vry Corp.): Do you have the post- and pre-equalization characteristics — do you have a slide of them?

Mr. Templin: No, I'm sorry I don't have a slide with me.

Mr. D'Arcy: Could you describe them for us?

Mr. Templin: At the present time there are at least three different pre-equalization characteristics being used by Hollywood studios. This is in addition to its 6 db per octave reproducing characteristic which all use. Some studios are recording with a flat characteristic over the entire frequency range. Others apply a 3.5 db boost at 50 cycles/sec with the high end recorded flat. Still others apply 6 db low-frequency pre-equalization at 50 cycles/sec and 4 db high-frequency pre-equalization at 8000 cycles/sec. Since the comple-

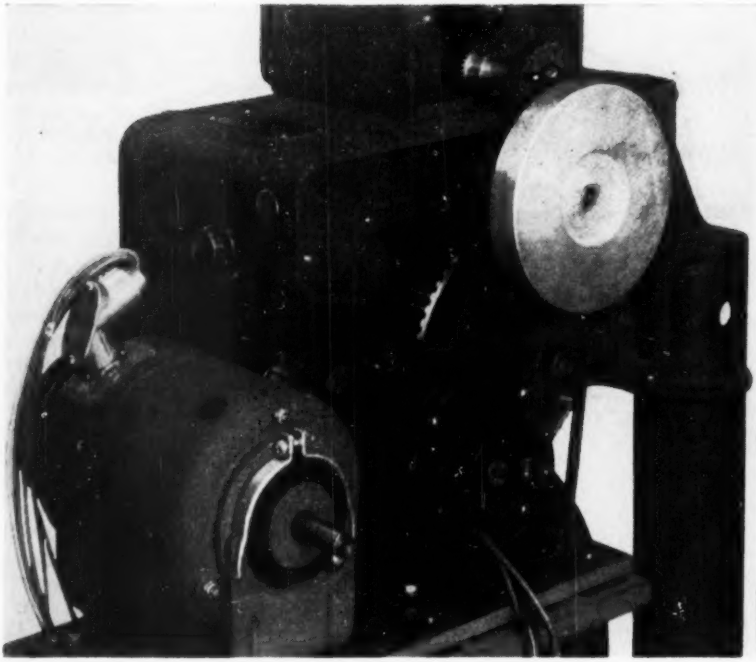

Fig. 9. Driving side of R8 Stereophonic Reproducer.

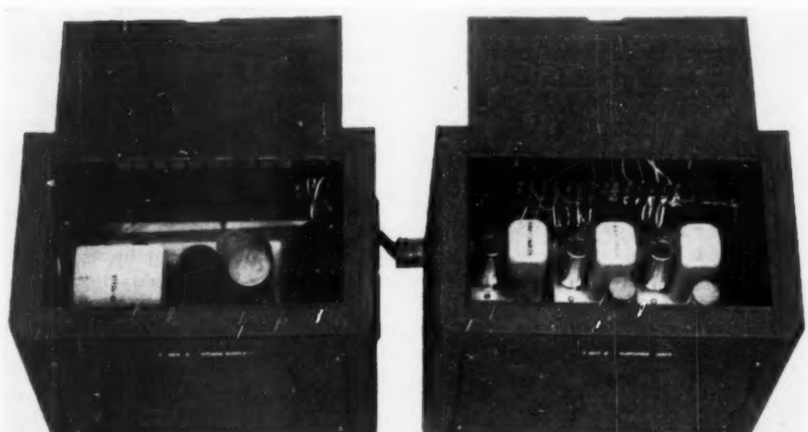

Fig. 10. Left, regulated power supply; right, preamplifier assembly.

ment of these characteristics must be added in the reproducing system we have three types of reproducing characteristics in use at the present time. Fortunately, under the leadership of the Motion Picture Research Council a movement is now under way to reach an agreement on a standard recording and reproducing characteristic.

Mr. D'Arcy: It's not an equipment manufacturing difference, but a studio difference with regard to the exact characteristics?

Mr. Templin: At the present time it exists because manufacturers were not in agreement and because individual studios made further changes.

Mauro Zambuto (I.F.E. Studios, N.Y.): Your monitoring device is an earphone set in which you're sending the central signal to both earphones, the left signal only to the left earphone, and the right signal only to the right earphone. I would like to know if any experiment has been made to determine how this compares with the objective effect of listening to the reproduction not through earphones but through loudspeakers? The other day we made a difference between binaural reproduction and stereophonic reproduction. It was said that under conditions prevailing up to now loudspeakers cannot provide binaural reproduction, but can work only on the stereophonic principle. Now, with headphones under these conditions you would have something close to binaural reproduction plus a certain general signal that you are feeding to both ears. I would like to know how this compares with theater conditions, where you don't have as much separation of the signals.

Mr. Templin: This method is to some extent a practical expedient based on a primary requirement of headset monitoring for a three-channel stereophonic system. A primary purpose is to get proper localization and movement of sound in conformance with the action seen by the camera. Although, as you point out, a binaural headset cannot exactly match the results obtained with a three-channel loudspeaker system, nevertheless it can give the effect of localization and of a smooth movement across the stage. On that basis it gives a very useful and satisfactory rendition of what is happening. If anybody is here who has actually been using this method at Fox or anywhere else, and would like to add a comment, I'd be very happy to have them do so.

John G. Frayne (Westrex Corp.): According to Mr. Grignon, who has been largely responsible for most of the work at Twentieth Century-Fox, the binaural monitoring is very necessary since it has shown a remarkably close correlation with the ultimate stereophonic effect. He says further that without it the mixer would be unable to cope with difficult problems of pickup.

Walter T. Selsted (Ampex Electric Corp.): Did I understand you correctly to say that the playback amplifier equalization characteristic was a simple 6 db per octave slope at the high end, or was there some post emphasis beyond that?

Mr. Templin: We mentioned the three types of equalization which are being used currently. We are able to use any of these three types in our recording circuit and by suitable post-equalization to provide a flat overall response.

Mr. Selsted: Which one do you recommend?

Mr. Templin: At the present time we are supplying whichever characteristic a particular customer requests. However, we're hoping that eventually all the suppliers and studios will agree to use the same one. Our own standard equipment for the last several years has been supplied with no high-frequency pre-equilization, and with $3\frac{1}{2}$ db low-frequency pre-equilization.

New Theater Sound System for Multipurpose Use

By J. E. VOLKMANN, J. F. BYRD, and J. D. PHYFE

This paper describes a new theater sound system based on the "building block" concept for general indoor theater or drive-in theater use. The system is readily adaptable for multichannel sound reproduction for heightening the dramatic effect of the three-dimensional and peripheral-vision types of pictures soon to be released by Hollywood. New preamplifiers, power amplifiers and power supplies are described with rack layouts for specific applications. Included is a new booth front wall control system for effecting either sound change-over or simultaneous sound and picture change-over, and for selecting various signal sources.

THE BASIC REQUIREMENTS for theater sound systems have remained the same substantially for two decades; however, the trend toward the use of multichannel systems is increasing and has been given impetus by recent three-dimensional and peripheral-vision types of picture presentation. Earlier attempts at employing stereophonic or multichannel sound systems, as exemplified in Walt Disney's *Fantasia*, failed largely because of their cost and complication, and also because the newer picture presentation techniques were not then available. It has required the blending of new sound and picture techniques to achieve a dramatic and satisfactory improvement in motion-picture entertainment, and to justify the cost of additional equipment.

Presented on May 1, 1953, at the Society's Convention at Los Angeles, by J. E. Volkmann, J. F. Byrd and J. D. Phyfe (who read the paper), Radio Corporation of America, RCA Victor Div., Theatre Equipment Engineering Group, Camden 2, N.J. (This paper was received August 27, 1953.)

The equipment described in this paper includes two amplifier rack assemblies and a booth front wall control system, for conventional soundfilm use, and a third rack for multichannel use.

Amplifier Racks

Figure 1 is the front view of one of the racks. This rack assembly is comprised of a voltage amplifier and compensator, monitor – emergency amplifier, emergency selector switch, power amplifier (one or two of them) and a single 5-amp exciter lamp power supply.

Figure 2 shows the rack with front covers removed. The amplifier, rotated for tube servicing, is shown in Fig. 3.

A novel method of mounting the units makes for easy servicing. Two brackets fitted with hollow bushings secure the chassis to the rack and permit 90° rotation. These bushings in the mounting brackets are sufficiently large to allow the wiring to pass through them for connection to the terminal boards. This rotational feature gives complete accessibility

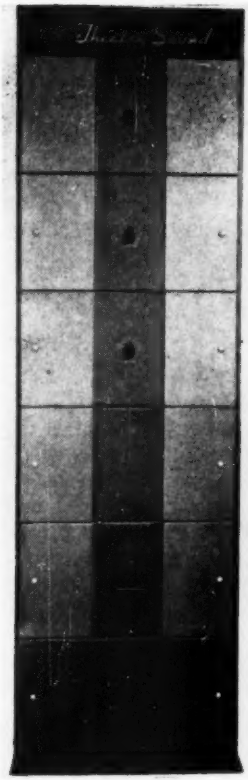

Fig. 1. Rack assembly, Type PG-330.

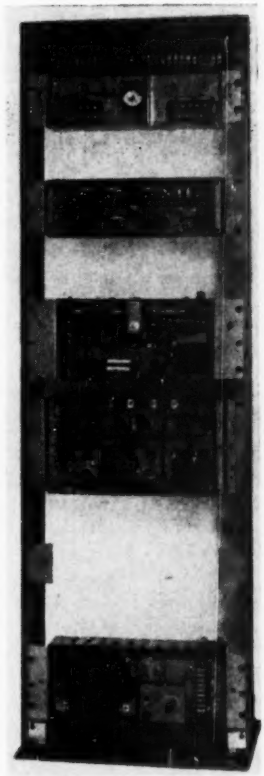

Fig. 2. Rack assembly with front covers removed, Type PG-330.

Fig. 3. Rack assembly with amplifiers rotated for servicing, Type PG-330.

to tubes and circuits and permits flush front covers. These covers in turn are secured with two quarter-turn fasteners and, when in place, cover the rack mounting screws. The height of the covers is designed to follow standard panel practice of $1\frac{3}{4}$-in. increments and except for the top cover carrying the logotype and monogram are of uniform dimensions. This improves the general appearance and at the same time permits flexibility in spacing the units on the rack without the necessity of filling in with various sizes of blank panels. The design permits the rack to be mounted close to the booth wall since all servicing can be done from the front.

At the top of the rack is the main terminal board for all external connections. The top unit is the emergency switch panel MI-9368. This selects either the normal channel, consisting of the voltage amplifier and compensator, and the power amplifier, or the monitor-emergency amplifier, to carry the show. A test jack, load resistor and switch are provided for making response measurements. Connecting the load resistor across the test jack automatically disconnects the stage speakers from the amplifier.

The second unit from the top is the

voltage amplifier and compensator MI-9357. This unit uses two 6J7 tubes in cascade with the input tube pentode connected and the output tube connected as a triode. Input and output transformers are employed and the unit works from and into 500 ohms. The compensating networks are brought to separate terminal boards for easy adjustment of the frequency response.

The third unit is the monitor-emergency amplifier MI-9335-B. This amplifier is a full gain channel of 102 db with a rated output of 15 watts. Two 6L6's are used in the output stage. Normally, this unit is padded down at the input when serving in its normal capacity as a monitor amplifier. The full gain of 102 db permits it to function as a complete amplifier channel should the occasion arise. The amplifier is well within Research Council specifications for distortion and noise.

The fourth unit is the power amplifier MI-9377. This amplifier is rated at 35 w with less than 1% distortion between 50 and 7500 cycles. Gain is 50 db and noise level -50 dbm. Frequency response is $\pm\frac{1}{2}$ db between 20 cycles and 15,000 cycles. Input to the amplifier is through a transformer and 500-ohm line. Output taps of 500, 250, 15 and 7.5 ohms are provided.

The input tube is a 6SL7-GT acting as a driver and phase inverter and operates into four 6L6's connected in parallel push-pull. Two 5U4G's serve as rectifiers and an OC3 and OD3 are connected in series for regulation of the screens of the 6L6's. 19-db of feedback is used through a tertiary winding in the output transformer to the cathode of the input tube. Due to the excellent filtering action of the regulator tubes in the screen voltage circuit of the 6L6's, it is possible to obtain a very low noise level without the use of a choke in the high voltage plate supply.

Space is provided on the rack to mount a second power amplifier should the power output requirements exceed 35 w.

The bottom unit on the rack is the exciter lamp power supply MI-9516. This employs a selenium-type rectifier in a bridge circuit to furnish filtered direct current to the exciter lamps. As an emergency feature 10-v alternating current from the power transformer may be substituted for the direct current by means of a toggle switch mounted in the unit. Adjustment of exciter lamp voltage is by means of a rheostat in the primary of the power transformer.

Figure 4 shows a rack assembly arranged for employing either plug-in soundhead preamplifiers or other external preamplifiers. The same type of mountings are used for the various units as in the previously described rack. Units which do not use tubes or do not require access to the top of the chassis for servicing are not provided with swivel mountings.

Figure 5 shows the same rack with covers removed, and in Fig. 6 it is shown with the amplifier rotated 90° for servicing the tubes.

Beginning from the top of the rack are: monitor amplifier MI-9370, compensator MI-9371, two 35-w power amplifiers MI-9377A, and two exciter lamp power supplies MI-9516, one for each soundhead. Space is provided for mounting a third exciter lamp power supply for a three-projector installation. In this event, the three units are mounted one above the other without spacing and three 7-in. front covers are supplied instead of two $10\frac{1}{2}$-in. covers.

Monitor Amplifier

The monitor amplifier is a 10-watt single-stage unit which includes several other functions. In it is built a switch for selecting either or both power amplifiers, a power supply for the preamplifiers, a test panel which includes a jack, load resistor, a switch for disconnecting the stage speakers and putting the load resistor across the jack, and a switch for

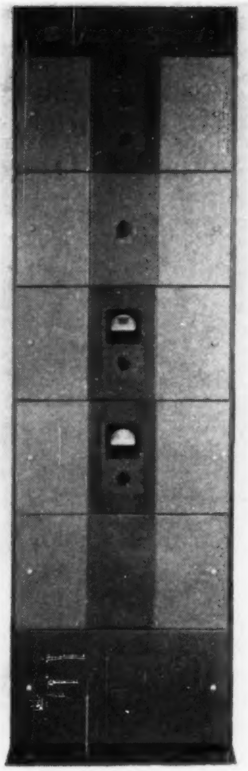

Fig. 4. Rack assembly, Type PG-340.

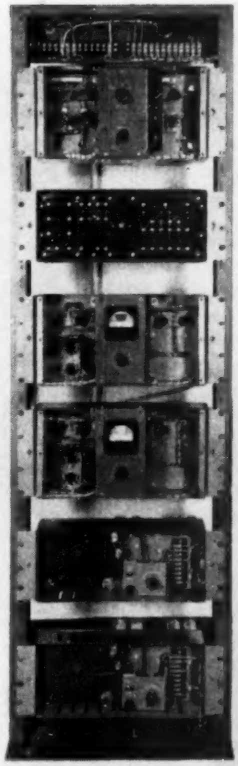

Fig. 5. Rack assembly with front covers removed, Type PG-340.

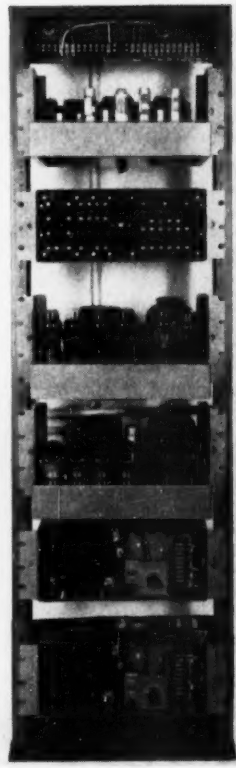

Fig. 6. Rack assembly with amplifiers rotated for servicing, Type PG-340.

utilizing the monitor amplifier power supply to provide power for the preamplifiers in event of failure of the regular preamplifier power supply. Switching of the power amplifier circuits is confined to the outputs, the inputs being wired in parallel. Impedances are automatically matched to the crossover network when either or both power amplifiers are in use.

Compensator

The compensator unit is electrically connected in the 500-ohm line between the soundhead preamplifiers and the power amplifier. RC networks are used to give high- and low-frequency boost and attenuation and an LC network is used to provide a variable low-pass filter. Provision is made to by-pass the compensation when desired.

Power Amplifiers

Two power amplifiers MI-9377A are supplied with this rack arrangement, providing 70-w of audio power. These power amplifiers are identical with those used in the previously described rack, except that in these amplifiers tube metering facilities are provided. A hinged panel mounted across the chassis contains a meter and a rotary switch for

checking all the tubes in the amplifier except the rectifier and regular tubes. The hinged panel swings down out of the way for easier access to the circuit components and wiring immediately behind the panel. This meter panel is also supplied as a kit and may be installed in the MI-9377 at any time.

Sound Change-over and Input Selector Units

Figure 7 shows the sound change-over unit MI-9748, and Fig. 8, the input selector MI-9749. These measure 21 × 7 × 4½ in. and are provided with hinged front covers secured by quarter-turn fasteners.

Mounted on the hinged cover of the sound change-over unit, top to bottom are: indicator light, volume control, change-over pushbutton, and soundhead motor switch. The lower part of the change-over cabinet contains the terminal boards for external wiring connections. This lower half of the cabinet may also be used as a conduit box for the horizontal conduit runs. The 21-in. height of the unit will in most cases eliminate the need for vertical conduit runs to the cabinet. This allows a neat front-wall arrangement requiring a minimum of conduit with a corresponding reduction in installation time. The cabinets also lend themselves very well with 4 × 4 wireways instead of conduit. This arrangement makes a very neat installation, and also facilitates tracing of the system wiring.

Figure 9 shows the inside of the change-over unit MI-9748.

Sound change-over is made by means of latching relays in the change-over units actuated by momentary contact pushbuttons. If desired, the picture can be changed over simultaneously with the sound by paralleling the foot switch and the pushbutton connections. With this arrangement the operator can change over the picture before the sound, if he chooses, by actuating the foot switch first.

Volume control is by means of a 500-ohm, tee-type attenuator adjustable in twenty 2-db steps, with cut-off to infinity on the last step.

Except for the front-cover arrangement the input selector (MI-9749) is quite similar in appearance to the MI-9748 change-over unit. A rotary switch provides means for selecting signal from

Fig. 7. Sound change-over unit, Type PG-330-340.

Fig. 8. Input selector unit, Type 330-340.

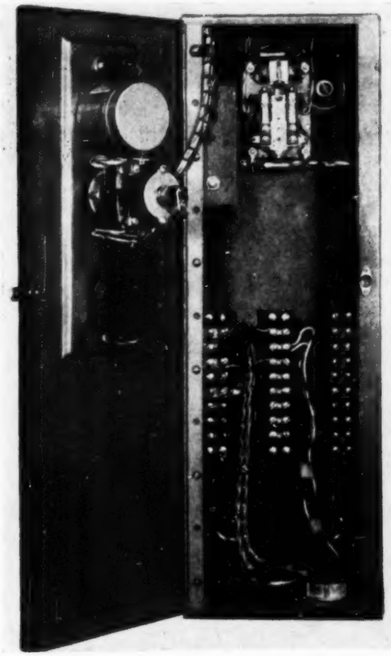

Fig. 9. Sound change-over unit with door open for servicing, Type 330-340.

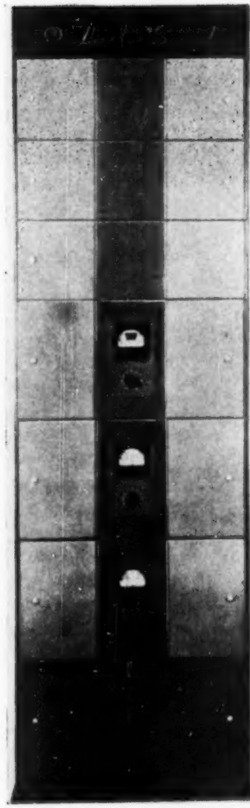

Fig. 10. Rack assembly for three-channel stereophonic service.

several input sources, and a small two-stage plug-in preamplifier MI-9362, mounted inside the cabinet, is employed to bring the signal up to zero level.

This amplifier can also serve as a plug-in soundhead preamplifier with the MI-9030 soundhead by means of an MI-9376 mounting box attachable to the soundhead. This arrangement would be used with the rack shown in Fig. 4.

Stereophonic Application

By rearrangement of units, a complete three-channel amplifier system for stereophonic and multiple-channel operation can be accommodated on one rack. Three MI-9357 preamplifiers and three MI-9377 or MI-9377A power amplifiers will provide three 115-db gain channels as shown in Fig. 10.

The frequency compensation provisions in the MI-9357 preamplifiers will permit adjusting the individual channels to any desired characteristic.

An MI-9554 monitor control unit, not shown but which will be available shortly, in conjunction with monitor amplifier MI-9335B will provide means for monitoring all channels either singly or simultaneously using a single monitor speaker. Bridging networks in the monitor control unit provide sufficient isolation between channels to avoid crosstalk.

Fig. 11. Soundhead type of triple-track magnetic reproducer, Type MI-9038.

A volume-control unit using a similar type of cabinet to the MI-9748 changeover, will also be available for adjusting the gain of the channels. This unit will include a three-gang variable attenuator as well as an individual control for adjusting the level of each channel and will be used in conjunction with MI-9038 triple-track magnetic reproducers. A view of the new MI-9038 reproducer which has been used successfully in a number of theaters showing the Warnerphonic picture *House of Wax* is shown in Fig. 11.

Since the original writing of this paper, a four-channel stereophonic sound system has been developed for the CinemaScope type of single-film presentation. This system is essentially the same as the three-channel sound system mentioned above with the addition of another channel in the same rack and the use of a four-channel "button-on" type of magnetic soundhead, Type MI-9010.

Basic Requirements for Auditory Perspective

By HARVEY FLETCHER

The fundamental requirements involved in a system capable of picking up orchestral music, transmitting it a long distance, and reproducing it in a large hall, are discussed in this paper.

In this electrical era one is not surprised to hear that orchestral music can be picked up in one city, transmitted a long distance, and reproduced in another. Indeed, most people think such things are commonplace. They are heard every night on the radio. However, anyone who appreciates good music would not admit that listening even to the best radio gives the emotional thrill experienced in the concert hall. Nor is it evident that a listener in a small room ever will be able to get the same effect as that experienced in a large hall, although it must be admitted that such a question is debatable. The proper answer will involve more than a consideration of only the physical factors.

This symposium describes principles and apparatus involved in the reproduction of music in large halls, the reproduction being of a character that may give even greater emotional thrills to music lovers than those experienced from the original music. This statement is based upon the testimony of those who have heard some of the few concerts reproduced by the apparatus which will be described in the papers of this symposium.

It is well known that when an orchestra plays, vibrations which are continually changing in form are produced in the air of the concert hall where the orchestra is located. An ideal transmission and reproducing system may be considered as one that produces a similar set of vibrations in a distant concert hall in which is executed the same time-sequence of changes that takes place in the original hall. Since such changes are different at different positions in the hall, the use of such an ideal system implies that at corresponding positions in the two halls this time-sequence should be the same. Obviously, this never can be true at every position unless the halls are the same size and shape; corresponding positions would not otherwise exist. Let us consider the case where the two halls are the same size and shape and also have the same acoustical properties. Let us designate the first hall in which the music originates by O, and the second one in

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which the music is reproduced by R. What requirements are necessary to obtain perfect reproduction from O into R such that any listener in any part of R will receive the same sound effects as if he were in the corresponding position in O?

Suppose there were interposed between the orchestra and the audience a flexible curtain of such a nature that it did not interfere with a free passage of the sound, and which at the same time had scattered uniformly over it microphones which would pick up the sound waves and produce a faithful electrical copy of them. Assume each microphone to be connected with a perfect transmission line which terminates in a projector occupying a corresponding position on a similar curtain in hall R. By a perfect transmission line is meant one that delivers to the projector electrical energy equal both in form and magnitude to that which it receives from the microphone. If these sound projectors faithfully transform the electrical vibrations into sound vibrations, the audience in hall R should obtain the same effect as those listening to the original music in hall O.

Theoretically, there should be an infinite number of such ideal sets of microphones and sound projectors, and each one should be infinitesimally small. Practically, however, when the audience is at a considerable distance from the orchestra, as usually is the case, only a few of these sets are needed to give good auditory perspective; that is, to give depth and a sense of extensiveness to the source of the music. The arrangement of some of these simple systems, together with their effect upon listeners in various parts of the hall, is described in the paper by Steinberg and Snow (p. 420).

In any practical system it is important to know how near these ideal requirements one must approach before the listener will be aware that there has been any degradation from the ideal. For example, it is well known that whenever a sound is suddenly stopped or started, the frequency band required to transmit the change faithfully is infinitely wide. Theoretically, then, in order to fulfill these ideal requirements for transmitting such sounds, all three elements in the transmission system should transmit all possible frequencies without change. Practically, because of the limitations of hearing, this is not necessary. If the intensities of some of the component frequencies required to represent such a change are below the threshold of audibility it is obvious that their elimination will not be detected by the average normal ear. Consequently, for high-grade reproduction of sounds it is obvious that, except in very special cases, the range of frequencies that the system must transmit is determined by the range of hearing rather than by the kind of sound that is being reproduced.

Tests have indicated that, for those having normal hearing, pure tones ranging in frequency from 20 to 20,000 cycles per second (cps) can be heard. In order to sense the sounds at either of these extreme limits, they must have very high intensity. In music these frequencies usually are at such low intensities that the elimination of frequencies below 40 cps and those above 15,000 cps produces no detectable difference in the reproduction of symphonic music. These same tests also indicate that the further elimination of frequencies beyond either of these limits did begin to produce noticeable effects, particularly on a certain class of sounds produced in the orchestra. For example, the elimination of all frequencies above 13,000 cps produced a detectable change in the reproduced sound of the snare drum, cymbals, and castanets. Also, the elimination of frequencies below 40 cps produced detectable differences in reproduced music of the base viol, the bass tuba, and particularly of the organ.

Within this range of frequencies the system (the combination of the micro-

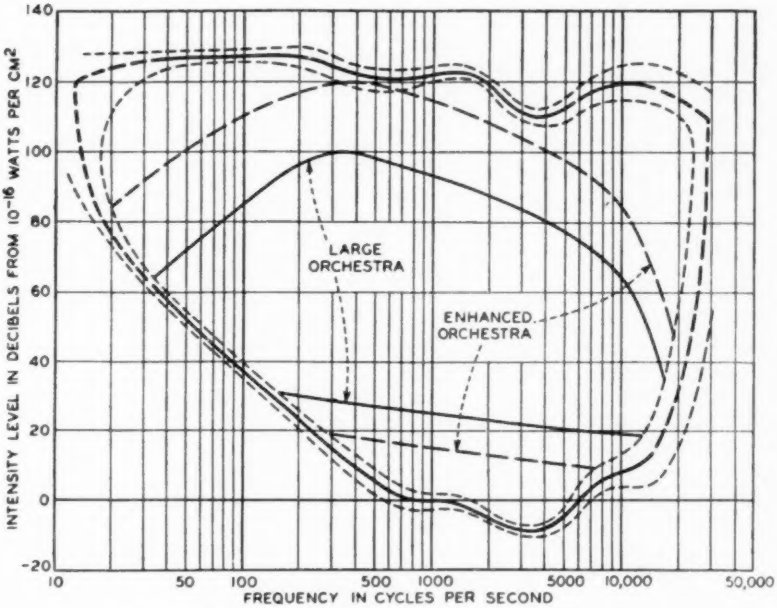

Fig. 1. Limits of audible sound as determined by recent tests.

phone, transmission line and loudspeaker) should reproduce the various frequencies with the same efficiency. Such a general statement sounds correct but a careful analysis of it would reveal that when any one tried to build such a system or tried to meet such a requirement he would have great difficulty in understanding what it meant.

For example, for reproducing all the frequencies within this band, a certain system may be said to have a uniform efficiency when it operates between two rooms under the condition that the pressure variation at a certain distance away from the sound projector is the same as the pressure variation at a certain position in front of the microphone. It is obvious, however, that in other positions in the two rooms this relation would not in general hold. Also, if the system were transferred into another pair of rooms the situation would be entirely changed. These difficulties and the way they were met are discussed in the papers of this symposium that deal with loudspeakers and microphones (p. 431) and with methods of applying the reproducing system to the concert hall.[1] It will be obvious from these papers that the criterion for determining the ideal frequency characteristics to be given to the system is arbitrary within certain limits. However, solving the problem according to criteria adopted produced a system that gave very satisfactory results.

Besides the requirement on frequency response just discussed, the system also must be capable of handling sound powers that vary through a very wide range. If this discussion were limited to the type of symphonic music that now is produced by the large orchestras, this range would be about 10,000,000 to 1, or 70 db. To reproduce such music then, the system should be capable of handling the smallest amount of power

without introducing extraneous noises approaching it in intensity, and also reproduce the most intense sounds without overloading any part of the transmission system. However, this range is determined by the capacities of the musical instruments now available and the man power that conveniently can be grouped together under one conductor. As soon as a system was built that was capable of handling a much wider range, the musicians immediately took advantage of it to produce certain effects that they previously had tried to obtain with the orchestra alone, but without success because of the limited power of the instruments themselves. For these reasons it seems clear that the desirable requirements for intensity range, as well as those for the frequency range, are determined largely by the ear rather than by the physical characteristic of any sound. An ideal transmission should, without introducing an extraneous audible sound, be capable of reproducing a sound as faintly as the ear can hear and as loudly as the ear can tolerate. Such a range has been determined with the average normal ear when using pure tones. The results of recent tests are shown in Fig. 1.

The ordinates are given in decibels above the reference intensity which is 10^{-16} watts per square centimeter. The values are for field intensities existing in an air space free from reflecting walls. The most intense peaks in music come in the range between 200 and 1000 cps. Taking an average for this range it may be seen that there is approximately a 100-db range in intensity for the music, provided about 10 db is allowed for the masking of sound in the concert hall even when the audience is quietest.

The music from the largest orchestra utilizes only 70 db of this range when it plays in a concert hall of usual size. To utilize the full capabilities of the hearing range the ideal transmission system should add about 10 db on the *pp* side and 20 db on the *ff* side of the range. The capacity of the sound projectors necessary to reach the maximum allowable sound that the ear can tolerate varies with the size of the room. A good estimate can be obtained by the following consideration.

If T is the time of reverberation of the hall in seconds, E the power of the sound source in watts, I the maximum energy density per cubic centimeter in joules, and V the volume of the hall in cubic centimeters, then it is well known that

$$I = \frac{1}{6 \log_e 10} \cdot \frac{ET}{V}. \qquad (1)$$

Measurements have shown that when the sound intensity in a free field reaches about 10^{-4} w/sq cm, the average person begins to *feel* the sound. This maximum value is approximately the same for all frequencies in the important audible range. Any higher intensities, and for some persons somewhat lower intensities, become painful and may injure the hearing mechanism. This intensity corresponds to an energy density I of 3×10^{-9} j. Using this figure as the upper limit to be tolerated by the human ear, then, the maximum power of the sound source must be given by

$$E = 4.1 \times 10^{-8} \frac{V}{T}. \qquad (2)$$

For halls like the Academy of Music in Philadelphia and Carnegie Hall in New York City, in which the volume V is approximately 2×10^{10} cu cm and the reverberation time about 2 sec, E, the power of the sound source, is approximately 400 w. For other halls it may be seen that the power required for this source is proportional to the volume of the hall and inversely proportional to the reverberation time. A person would experience the sense of *feeling* when closer than about 10 m to such a source of 400 w power, even in free open space. Hence it would be unwise to have seats closer than 10 or 15 m from the stage when such powers are to be used.

These, then, are the general fundamental requirements for an ideal transmission system. How near they can be realized with apparatus that we now know how to build will be discussed in the papers included in this symposium.

A system approximately fulfilling these requirements was constructed and used to reproduce the music played by the Philadelphia Orchestra. The first public demonstration was given in Constitution Hall, Washington, D.C., on the evening of April 27, 1933, under the auspices of the National Academy of Sciences. At that time, Dr. Stokowski, Director of the Philadelphia Orchestra, manipulated the electric controls from a box in the rear of Constitution Hall while the orchestra, led by Associate Conductor Smallens, played in the Academy of Music in Philadelphia.

Three microphones of the type described in the paper by Wente and Thuras (p. 431) were placed before the orchestra in Philadelphia, one on each side and one in the center at about 20 ft in front of and 10 ft above the first row of instruments in the orchestra. The electrical vibrations generated in each of these microphones were amplified by voltage amplifiers and then fed into a transmission line which was extended to Washington by means of telephone cable. The construction of these lines, the equipment used with them, and their electrical properties, are described in the paper by Affel, Chestnut, and Mills.[2] In Constitution Hall at Washington, D.C., these transmission lines were connected to power amplifiers. The types of power amplifiers and voltage amplifiers used are described in the paper by Scriven.[3] The output of these amplifiers fed three sets of loudspeakers like those described in the paper by Wente and Thuras. They were placed on the stage in Constitution Hall in positions corresponding to the microphones in the Academy of Music, Philadelphia.

Judging from the expression of those who heard this concert, the development of this system has opened many new possibilities for the reproduction and transmission of music that will create even a greater emotional appeal than that obtained when listening to the music coming directly from the orchestra through the air.

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REPRINT

Physical Factors in Auditory Perspective

By J. C. STEINBERG and W. B. SNOW

In considering the physical factors affecting it, auditory perspective is defined in this paper as being reproduction which preserves the spatial relationship of the original sounds. Ideally, this would require an infinite number of separate microphone-to-speaker channels; practically, it is shown that good auditory perspective can be obtained with only two or three channels.

ABILITY to localize the direction, and to form some judgment of the distance from a sound source under ordinary conditions of listening, are matters of common experience. Because of this faculty an audience, when listening directly to an orchestral production, senses the spatial relations of the instruments of the orchestra. This spatial character of the sounds gives to the music a sense of depth and of extensiveness, and for perfect reproduction should be preserved. In other words, the sounds should be reproduced in true *auditory perspective.*

In the ordinary methods of reproduction, where only a single loudspeaking system is used, the spatial character of the original sound is imperfectly preserved. Some of the depth properties of the original sound may be conveyed by such a system,[1] but the directional properties are lost because the audience tends to localize the sound as coming from the direction of a single source, the loudspeaker. Ideally, there are two ways of reproducing sounds in true auditory perspective. One is binaural reproduction which aims to reproduce in a distant listener's ears, by means of head receivers, exact copies of the sound vibrations that would exist in his ears if he were listening directly. The other method, which was described in the first paper of this series, uses loudspeakers and aims to reproduce in a distant hall an exact copy of the pattern of sound vibration that exists in the original hall. In the limit, an infinite number of microphones and loudspeakers of infinitesimal dimensions would be needed.

Far less ideal arrangements, consisting of as few as two microphone-loudspeaker sets, have been found to give good auditory perspective. Hence, it is not necessary to reproduce in the distant hall an exact copy of the vibrations existing in the original hall. What physical

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properties of the waves must be preserved then, and how are these properties preserved by various arrangements of two- and three-channel loudspeaker reproducing systems? To answer these questions, some very simple localization tests have been made with such systems. Perhaps attention can be focused more easily on their important properties by considering briefly the results of these tests.

Localization Afforded by Multichannel Systems

In Fig. 1 is shown a diagram of the experimental setup that was used. The microphones, designated as *LM* (left), *CM* (center), and *RM* (right), were set on a "pickup" stage that was marked out on the floor of an acoustically treated room. The loudspeakers, designated as *LS*, *CS*, and *RS*, were placed in the front end of the auditorium at the Bell Telephone Laboratories and were concealed from view by a curtain of theatrical gauze. The average position of a group of twelve observers is indicated by the cross in the rear center part of the auditorium.

The object of the tests was to determine how a caller's position on the pickup stage compared with his apparent position as judged by the group of observers in the auditorium listening to the reproduced speech. Words were uttered from some 15 positions on the pickup stage in random order. The 9 positions shown in Fig. 1 were always included in the 15, the remaining positions being introduced to minimize memory effects. The reproducing system was switched off while the caller moved from one position to the other.

In the first series of tests, the majority of the observers had no previous experience with the setup. They simply were given a sheet of coordinate paper with a single line ruled on it to indicate the line of the gauze curtain and asked to locate the apparent position of the caller with respect to this line. Following these tests, the observers were permitted to listen to speech from various announced positions on the pickup stage. This gave them some notion of the approximate outline of what might be called the "virtual" stage. These tests then were repeated. As there was no significant difference in results, the data from both tests have been averaged and are shown in Fig. 1.

The small diagram at the top of Fig. 1 shows the caller's positions with respect to the microphone positions on the pickup stage. The corresponding average apparent positions when reproduced are shown with respect to the curtain line and the loudspeaker positions. The type of reproduction is indicated symbolically to the right of the apparent position diagrams.

With three-channel reproduction there is a reasonably good correspondence between the caller's actual position on the pickup stage and his apparent position on the virtual stage. Apparent positions to the right or left correspond with actual positions to the right or left, and apparent front and rear positions correspond with actual front and rear positions. Thus the system afforded lateral or "angular" localization as well as fore and aft or "depth" localization. For comparison, there is shown in the last diagram the localization afforded by direct listening. The crosses indicate a caller's position in back of the gauze curtain and the circles indicate his apparent position as judged by the observers listening to his speech directly. In both cases, as the caller moved back in a straight line on the left or right side of the stage, he appeared to follow a curved path pulling in toward the rear center; e.g., compare the caller positions 1, 2, 3, with the apparent positions 1, 2, 3. This distortion was somewhat greater for three-channel reproduction than for direct listening.

The results obtained with the two-channel system show two marked differences from those obtained with three-channel reproduction. Positions on the

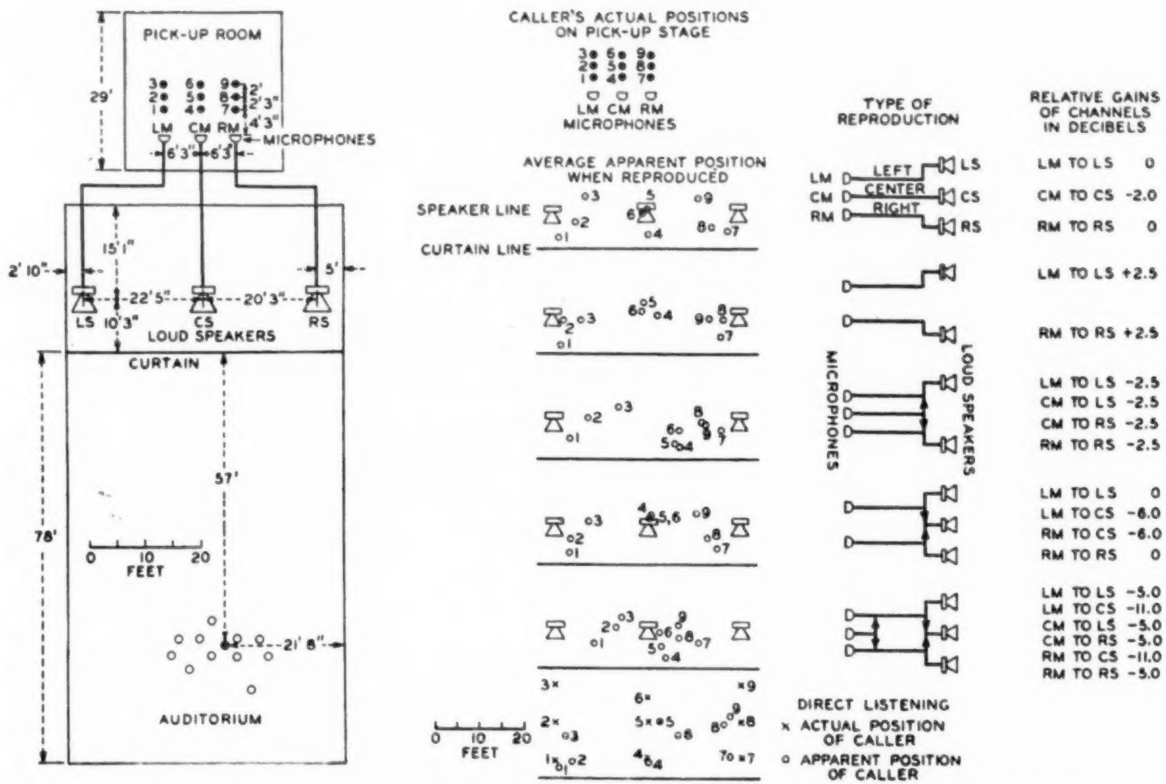

Fig. 1. Diagram of arrangement (left) for sound localization tests and (right) the results obtained.

center line of the pickup stage (i.e., 4, 5, 6) all appear in the rear center of the virtual stage, and the virtual stage depth for all positions is reduced. The virtual stage width, however, is somewhat greater than that obtained with three-channel reproduction.

Bridging a third microphone across the two-channel system had the effect of pulling the center-line positions 4, 5, and 6 forward, but the virtual stage depth remained substantially that afforded by two-channel reproduction, while the virtual stage width was decreased somewhat. In this and the other bridged arrangements the bridging circuits employed amplifiers, as represented by the arrows in Fig. 1, in such a way that there was a path for speech current only in the indicated direction.

Bridging a third loudspeaker across the two-channel system had the effect of increasing the virtual stage depth and decreasing the virtual stage width, but positions on the center line of the pickup stage appeared in the rear center of the virtual stage as in two-channel reproduction.

Bridging both a third microphone and a third loudspeaker across the two-channel system had the effect of reducing greatly the virtual stage width. The width could be restored by reducing the bridging gains, but fading the bridged microphone out caused the front line of the virtual stage to recede at the center, whereas fading the bridged loudspeaker out reduced the virtual stage depth. No fixed set of bridging gains was found that would enable the arrangement to create the virtual stage created by three independent channels. The gains used in obtaining the data shown in Fig. 1 are indicated at the right of the symbolic circuit diagrams.

Factors Affecting Depth Localization

Before attempting to explain the results that have been given in the foregoing, it may be of interest to consider certain additional observations that bear more specifically upon the factors that enter into the "depth" and "angular" localization of sounds. The microphones on the pickup stage receive both direct and reverberant sound, the latter being sound waves that have been reflected about the room in which the pickup stage is located. Similarly, the observer receives the reproduced sounds directly and also as reverberant sound caused by reflections about the room in which he listens. To determine the effects of these factors, the following three tests were made:

1. Caller remained stationary on the pickup stage and close to microphone, but the loudness of the sound received by the observer was reduced by gain control. This was loudness change without a change in ratio of direct to reverberant sound intensity.

2. Caller moved back from microphone, but gain was increased to keep constant the loudness of the sound received by the observer. This was a change in the ratio of direct to reverberant sound intensity without a loudness change.

3. Caller moved back from microphone, but no changes were made in the gain of the reproducing system. This changed both the ratio and the loudness.

All of the observers agreed that the caller appeared definitely to recede in all three cases. That is, either a reduction in loudness or a decrease in ratio of direct to reverberant sound intensity, or both, caused the sound to appear to move away from the observer. Position tests using variable reverberation with a given pickup stage outline showed that increasing the reverberation moved the front line of the virtual stage toward the rear, but had slight effect upon the rear line. When the microphones were placed outdoors to eliminate reverberation, reducing the loudness either by changing circuit gains or by increasing the distance between caller and microphone moved the whole virtual stage farther away. It is because of these

effects that all center-line positions on the pickup stage appeared at the rear of the virtual stage for two-channel reproduction.

It has not been found possible to put these relationships on a quantitative basis. Probably a given loudness change or a given change in ratio of direct to reverberant sound intensity, causes different sensations of depth depending upon the character of the reproduced sound and upon the observer's familiarity with the acoustic conditions surrounding the reproduction. Since the depth localization is inaccurate even when listening directly, it is difficult to obtain sufficiently accurate data to be of much use in a quantitative way. Because of this inaccuracy, good auditory perspective may be obtained with reproduced sounds even though the properties controlling depth localization depart materially from those of the original sound.

Angular Localization

Fortunately, the properties entering into lateral or angular localization permit more quantitative treatment. In dealing with angular localization, it has been found convenient to neglect entirely the effects of reverberant sound and to deal only with the properties of the sound waves reaching the observer's ears without reflections. The reflected waves or reverberant sounds do appear to have a small effect on angular localization, but it has not been found possible to deal with such sound in a quantitative way. One of the difficulties is that, because of differences in the build-up times of the direct and reflected sound waves, the amount of direct sound relative to reverberant sound reaching the observer's ears for impulsive sounds such as speech and music is much greater than would be expected from steady-state methods of dealing with reverberant sound.

For the case of a plane progressive wave from a single sound source, and where the observer's head is held in a fixed position, there are apparently only three factors that can assist in angular localization: namely, phase difference, loudness difference, and quality difference between the sounds received by the two ears.

In applying these factors to the localization of sounds from more than one source, as in the present case, the effects of phase differences have been neglected. It is difficult to see how phase differences in this case can assist in localization in the ordinary way. The two remaining factors, loudness and quality differences, both arise from the directivity of hearing. This directivity probably is due in part to the shadow and diffraction effects of the head and to the differences in the angle subtended by the ear openings. Measurements of the directivity with a source of pure tone located in various positions around the head in a horizontal plane have been reported by Sivian and White.[2] From these measurements, the loudness level differences between near and far ears have been determined for various frequencies. These differences are shown in Fig. 2 from which, using the pure tone data given, similar loudness level differences for complex tones may be calculated. Such calculated differences for speech are shown in Fig. 3.

As may be inferred from the varying shapes of the curves of Fig. 2, the directive effects of hearing introduce a frequency distortion more or less characteristic of the direction from which the sound comes. Thus the character or quality of complex sounds varies with the angle of the source. There are quality differences at each ear for various angles of source, and quality differences between the two ears for a given angle of source. In Fig. 4 is shown the frequency distortion at the right ear when a source of sound is moved from a position on the right to one on the left of an observer. It is a graph of the "difference" values of Fig. 2 for an angle of 90°. Frequencies above 4,000 cycles per second are reduced by as much as 15 to 30 db. This

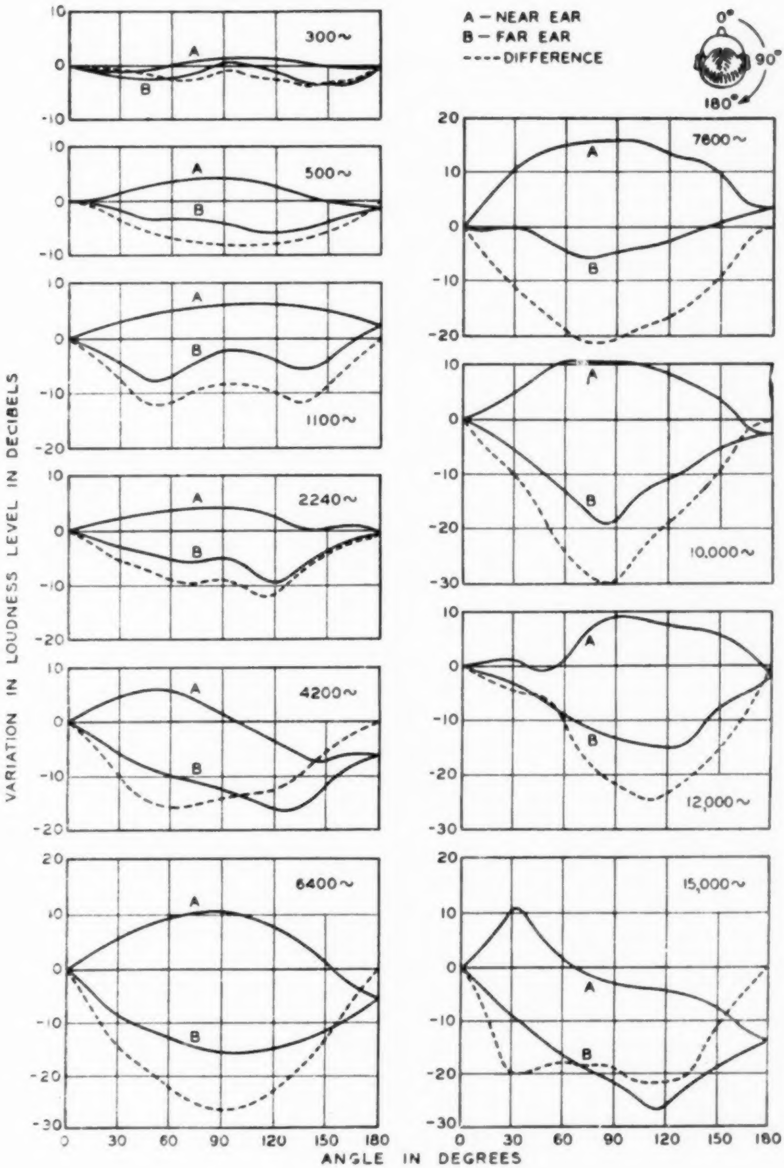

Fig. 2. Variation in loudness level as a sound source is rotated in a horizontal plane around the head.

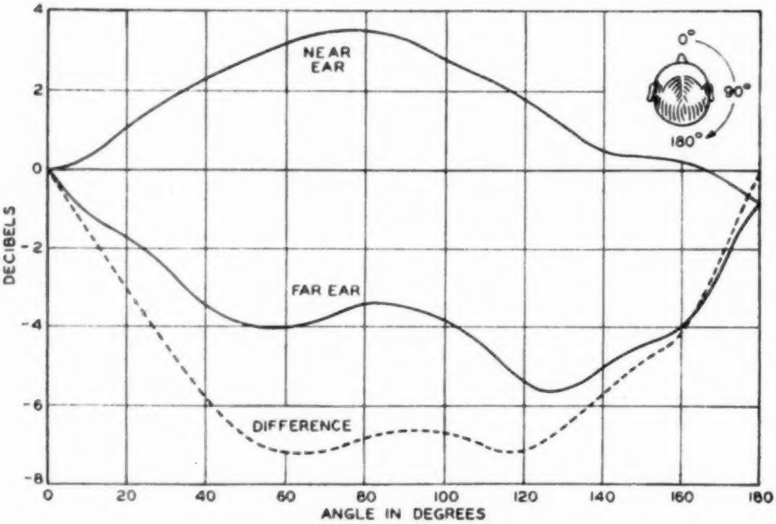

Fig. 3. Variation in loudness as a speech source is rotated in a horizontal plane around the head.

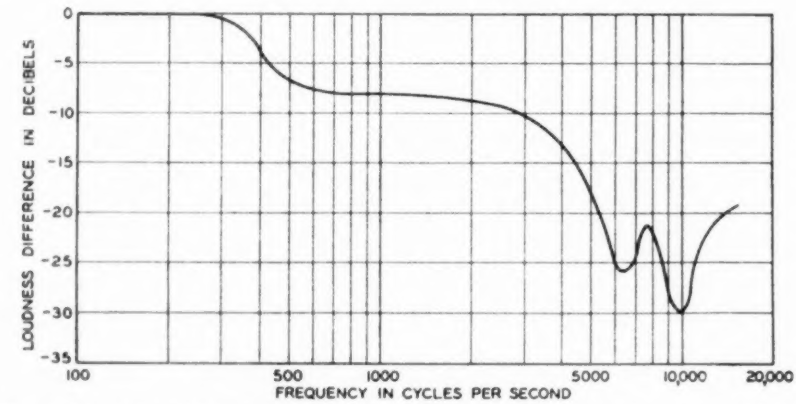

Fig. 4. Loudness difference produced in the right ear when a source of pure tone is moved from the right to the left of an observer.

amount of distortion is sufficient to affect materially the quality of speech, particularly as regards the loudness of the sibilant sounds.

Reference to the difference curve of Fig. 3 shows that if, for example, a source of speech is 20° to the right of the median plane the speech heard by the right ear is 3 db louder than that heard by the left ear. A similar difference exists when the angle is 167°. Presumably, when the right ear hears speech 3 db louder than the left, the observer localizes the sound as coming from a position 20° or 167° to the right, depending upon the quality of the speech. If this be as-

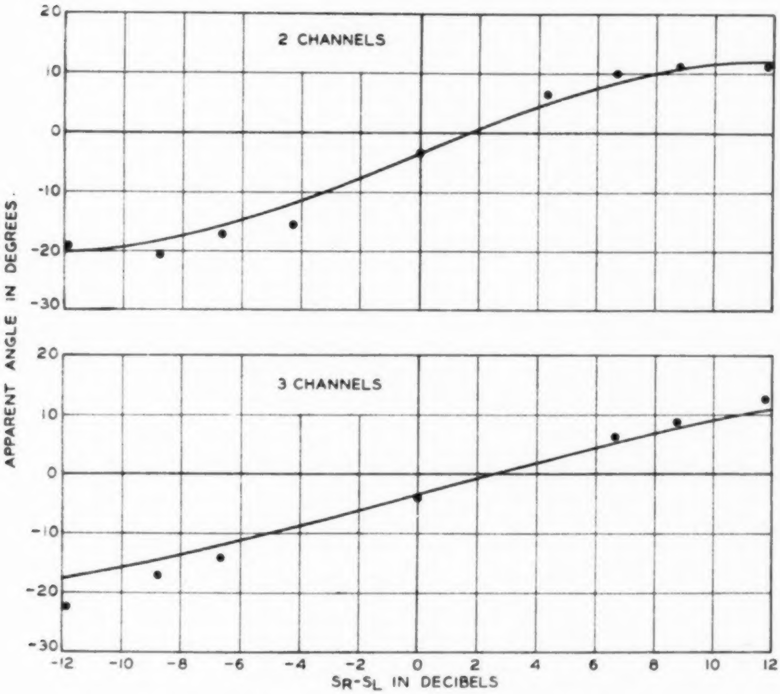

Fig. 5. Calculated and observed apparent angles for two- and three-channel reproduction.

sumed to be true, even though the difference is caused by the combination of sounds of similar quality from several sources, it should be possible to calculate the apparent angle.

Loudness Theory of Localization

Upon this assumption the apparent angle of the source as a function of the difference in decibels between the speech levels emitted by the loudspeakers of the two- and three-channel systems has been calculated. Each loudspeaker contributes an amount of direct sound loudness to each ear, depending upon its distance from, and its angular position with respect to, the observer. These contributions were combined on a power basis to give a resultant loudness of direct sound at each ear, from which the difference in loudness between the two ears was determined. The calculated results for the two- and three-channel systems are shown by the solid lines in Fig. 5. The y-axis shows the apparent angle, positive angle being measured in a clockwise direction. The x-axis shows the difference in decibels between the speech levels from the right and left loudspeakers. The points are observed values taken from Fig. 1. The observed apparent angles were obtained directly from the average observer's location and the average apparent positions shown in Fig. 1. The speech levels from each of the loud-speakers were calculated for each position on the pickup stage. This was done by assuming that the waves arriving at the microphone had relative levels inversely proportional to the

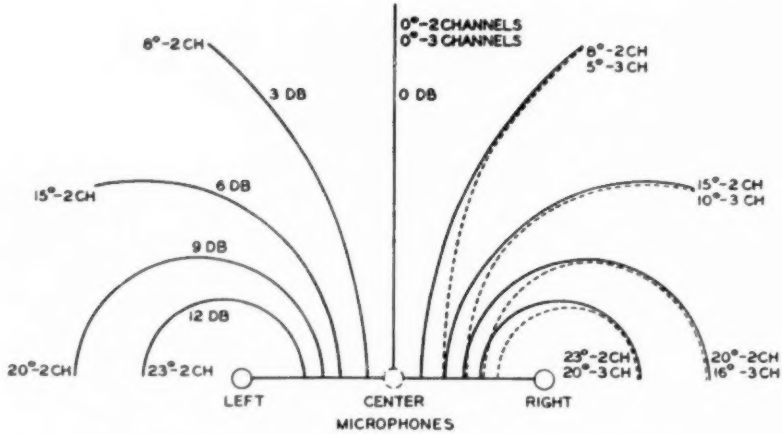

Fig. 6. Pickup stage contour lines of constant apparent angle.

squares of the distances traversed. By correcting for the angle of incidence and for the known relative gains of the systems, the speech levels from the loudspeakers were obtained.

A comparison of the observed and calculated results seems to indicate that the loudness difference at the two ears accounts for the greater part of the apparent angle of the reproduced sounds. If this is true, the angular location of each position on the virtual stage results from a particular loudness difference at the two ears produced by the speech coming from the loudspeakers. When three channels are used a definite set of loudspeaker speech levels exists for each position on the pickup stage. To create these same sets of loudspeaker speech levels with the three-microphone three-loudspeaker bridging arrangement already discussed, it would be necessary to change the bridging gains for each position on the pickup stage. Hence it could not be expected that the arrangement as used (i.e., with fixed gains) would create a virtual stage identical with that created by three-channel reproduction. However, with proper technique, bridging arrangements on a given number of channels can be made to give better reproduction than would be obtained with the channels alone.

Experimental Verification of Theory

Considerations of loudness difference indicate that all caller positions on the pickup stage giving the same relative loudspeaker outputs should be localized at the same virtual angle. The solid lines of Fig. 6 show a stage layout used to test this hypothesis with the two-channel system. All points on each line have a constant ratio of distances to the microphones. The resulting direct sound differences in pressure expressed in decibels and the corresponding calculated apparent angles are indicated beside the curves. The apparent angles were calculated for an observing position on a line midway between the two loudspeakers but at a distance from them equal to the separation between them. The microphones were turned face up at the height of the talker's lips to eliminate quality changes caused by changing incidence angle. It was found that a caller walking along one of these lines maintained a fairly constant virtual angle. For caller positions far from the microphones the observed angles were somewhat greater than those computed.

For highly reverberant conditions, the tendency was toward greater calculated than observed angles. Reverberation also decreased the accuracy of localization.

A change of relative channel gain caused a change in virtual angle as would be expected from loudness difference considerations. For instance, if the caller actually walked the left 3-db line, he seemed to be on the 6-db line when the left channel gain was raised 3 db. Many of the effects of moving about the pickup stage could be duplicated by volume control manipulation as the caller walked forward and backward on the center path. With a bridged center microphone substituted for the two side microphones similar effects were possible and, in addition, the caller by speaking close to the microphone could be brought to the front of the virtual stage.

For observing positions near the center of the auditorium the observed angles agreed reasonably well with calculations based only upon loudness differences. As the observer moved to one side, however, the virtual source shifted more rapidly toward the nearer loudspeaker than was predicted by the computations. This was true of reproduction in the auditorium, both empty and with damping simulating an audience, and outdoors on the roof. Computations and experiment also show a change in apparent angle as the observer moves from front to rear, but its magnitude is smaller than the error of an individual localization observation. Consequently, observers in different parts of the auditorium localize given points on the pickup stage at different virtual angles.

Because the levels at the three microphones are not independent, and because the desired contours depend upon the effects at the ears, a three-channel stage is not as simple to lay out as a two-channel stage. For a given observing position, however, a set of contour lines can be calculated. The dashed lines at the right of Fig. 6 show four contours thus calculated for the circuit condition of Fig. 1 and the observing position previously mentioned. The addition of the center channel reduces the virtual angle for any given position on the pickup stage by reducing the resultant loudness difference at the ears. Although the three-channel contours approach the two-channel contours in shape at the back of the stage, a given contour results in a greater virtual angle for two- than for three-channel reproduction.

Similar effects were obtained experimentally. As in two-channel reproduction, movements of the caller could be simulated by manipulation of the channel gains. From an observing standpoint the three-channel system was found to have an important advantage over the two-channel system in that the shift of the virtual position for side observing positions was smaller.

Effects of Quality

If the quality from the various loudspeakers differs, the quality of sound is important to localization. When the two-channel microphones were so arranged that one picked up direct sound and reverberation while the other picked up mostly reverberation, the virtual source was localized exactly in the "direct" loudspeaker until the power from the "reverberant" loudspeaker was from 8 to 10 db greater. In general, localization tends toward the channel giving most natural or "close-up" reproduction, and this effect can be used to aid the loudness differences in producing angular localization.

Principal Conclusions

The principal conclusions that have been drawn from these investigations may be summarized as follows:

1. Of the factors influencing angular localization, loudness difference of direct sound seems to play the most important part; for certain observing positions the effects can be predicted reasonably well

from computations. When large quality differences exist between the loudspeaker outputs, the localization tends toward the more natural source. Reverberation appears to be of minor importance unless excessive.

2. Depth localization was found to vary with changes in loudness, the ratio of direct to reverberant sound, or both, and in a manner not found subject to computational treatment. The actual ratio of direct to reverberant sound, and the change in the ratio, both appeared to play a part in an observer's judgment of stage depth.

3. Observers in various parts of the auditorium localize a given source at different virtual positions, as is predicted by loudness computations. The virtual source shifts to the side of the stage as the observer moves toward the side of the auditorium. Although quantitative data have not been obtained, qualitative data on these effects indicate that the observed shift is considerably greater than that computed. Moving backward and forward in the auditorium appears to have only a small effect on the virtual position.

4. Because of these physical factors controlling auditory perspective, point-for-point correlation between pickup stage and virtual stage positions is not obtained for two- and three-channel systems. However, with stage shapes based upon the ideas of Fig. 6, and with suitable use of quality and reverberation, good auditory perspective can be produced. Manipulation of circuit conditions probably can be used advantageously to heighten the illusions or to produce novel effects.

5. The three-channel system proved definitely superior to the two-channel by eliminating the recession of the center-stage positions and in reducing the differences in localization for various observing positions. For musical reproduction, the center channel can be used for independent control of soloist renditions. Although the bridged systems did not duplicate the performance of the physical third channel, it is believed that with suitably developed technique their use will improve two-channel reproduction in many cases.

6. The application of acoustic perspective to orchestral reproduction in large auditoriums gives more satisfactory performance than probably would be suggested by the foregoing discussions. The instruments near the front are localized by every one near their correct positions. In the ordinary orchestral arrangement, the rear instruments will be displaced in the reproduction depending upon the listener's position, but the important aspect is that every auditor hears differing sounds differing places on the stage and is not particularly critical of the exact apparent positions of the sounds so long as he receives a spatial impression. Consequently two-channel reproduction of orchestral music gives good satisfaction, and the difference between it and three-channel reproduction for music probably is less than for speech reproduction or the reproduction of sounds from moving sources.

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1. Joseph P. Maxfield, "Some physical factors affecting the illusion in sound motion pictures," *J. Acoust. Soc. Am.*, *3:* 69–80, July 1931.
2. L. J. Sivian and S. D. White, "Minimum audible sound fields," *J. Acoust. Soc. Am.*, *4:* 288–321, Apr. 1933.

REPRINT

Loudspeakers and Microphones for Auditory Perspective

By E. C. WENTE and A. L. THURAS

In ordinary radio broadcast of symphony music, the effort is to create the effect of taking the listener to the scene of the program, whereas in reproducing such music in a large hall before a large gathering the effect required is that of transporting the distant orchestra to the listeners. Lacking the visual diversion of watching the orchestra play, such an audience centers its interest more acutely in the music itself, thus requiring a high degree of perfection in the reproducing apparatus both as to quality and as to the illusion of localization of the various instruments. Principles of design of the loudspeakers and microphones used in the Philadelphia-Washington experiment are treated at length in this paper.

As EARLY as 1881 a large-scale musical performance was reproduced by telephone instruments at the Paris Electrical Exhibition. Microphones were placed on the stage of the Grand Opera and connected by wires to head receivers at the exposition. It is interesting to note that separate channels were provided for each ear so as to give to the music perceived by the listener the "character of relief and localization." With head receivers it is necessary to generate enough sound of audible intensity to fill only a volume of space enclosed between the head receiver and the ear. As no amplifiers were available, the production of enough sound to fill a large auditorium would have been entirely outside the range of possibilities. With the advent of telephone amplifiers, microphone efficiency could be sacrificed to the interest of good quality where, as in the reproduction of music, this was of primary interest. When amplifiers of greater output power capacity were developed, loudspeakers were introduced to convert a large part of the electrical power into sound so that it could be heard by an audience in a large auditorium. Improvements have been made in both microphones and loudspeakers, resulting in very acceptable quality of reproduction of speech and music; as is found, for instance, in the better class of motion-picture theaters.

Presented January 23–26, 1934, as the third paper at the Symposium on Wire Transmission of Symphonic Music and Its Reproduction in Auditory Perspective, at the Winter Convention of the American Institute of Electrical Engineers, in New York City, by E. C. Wente, Bell Telephone Laboratories, and the late A. L. Thuras; reprinted here from *Bell Sys. Tech. J., 13:* 259–277, Apr. 1934 (also published in *Elec. Eng., 53:* 17–24, Jan. 1934).

In the reproduction, in a large hall, of the music of a symphony orchestra the approach to perfection that is needed to satisfy the habitual concert audience undoubtedly is closer than that demanded for any other type of musical performance. The interest of the listener here lies solely in the music. The reproduction therefore should be such as to give to a lover of symphonic music esthetic satisfaction at least as great as that which would be given by the orchestra itself playing in the same hall. This is more than a problem of instrument design, but this paper will be restricted to a discussion of the requirements that must be met by the loudspeakers and microphones, and to a description of the principles of design of the instruments used in the transmission of the music of the Philadelphia Orchestra from Philadelphia to Constitution Hall in Washington. Some of the requirements are found in the results of measurements that have been made on the volume and frequency ranges of the music produced by the orchestra.

General Considerations

The acoustic powers delivered by the several instruments of a symphony orchestra, as well as by the orchestra as a whole, have been investigated by Sivian, Dunn and White. Figure 1 was drawn on the basis of the values published by them.[1] The ordinates of the horizontal lines give the values of the peak powers within the octaves indicated by the positions of the lines. For a more exact interpretation of these values the reader is referred to the original paper, but the chart here given will serve to indicate the power that a loudspeaker must be capable of delivering in the various frequency regions, if the reproduced music is to be as loud as that given by the orchestra itself. However, it was the plan in the Philadelphia-Washington experiment to reproduce the orchestra, when desired, at a level 8 or 10 db higher, so that with three channels each loudspeaking system had to be able to deliver two or three times the powers indicated in Fig. 1. Sivian, Dunn and White also found that for the whole frequency band the peak powers in some cases reached values as high as 65 w. In order to go 8 db above this value, each channel would have to be capable of delivering in the neighborhood of 135 w.

The chart (Fig. 1) shows that the orchestra delivers sound of comparable intensity throughout practically the whole audible range. Although it is conceivable that the ear would not be capable of detecting a change in quality if some of the higher or lower frequencies were suppressed, measurements published by W. B. Snow[2] show that for any change in quality in any of the instruments to be undetectable the frequency band should extend from about 40 to about 13,000 cps. The necessary frequency ranges that must be transmitted to obviate noticeable change in quality for the different orchestral instruments are indicated in the chart of Fig. 2, which is taken from the paper by Snow.

Thus far only the sound generated by the orchestra itself has been considered. However, it is well known that the esthetic value of orchestral music in a concert hall is dependent to a very great extent upon the acoustic properties of the hall. At first thought one might be inclined to leave this out of account in considering the reproduction by a loud-speaking system, as one should normally choose a hall known to have satisfactory acoustics for an actual orchestra. There would be no further problem in this if the orchestral instruments and the loudspeaker radiated the sound uniformly in all directions, but some of the important instruments are quite directive; i.e., they radiate much the greater portion of their sound through a relatively small angle. As an example, a polar diagram giving the relative intensities of the sound radiated in various directions by the violin is given in Fig. 3, which is taken from a paper pub-

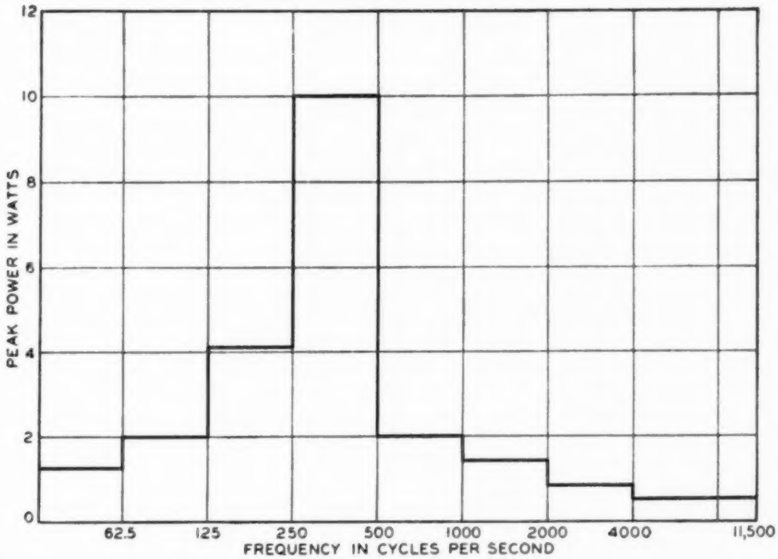

Fig. 1. Peak powers delivered by an orchestra within various frequency regions.

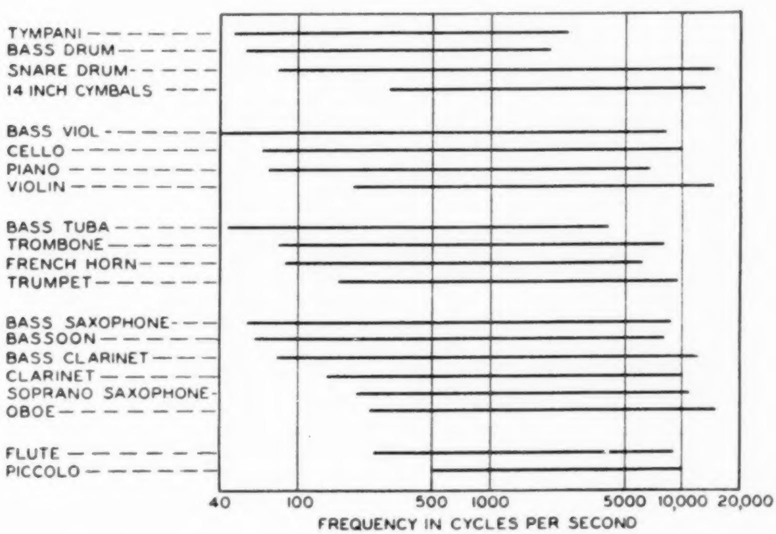

Fig. 2. Frequency transmission range required to produce no noticeable distortion for orchestral instruments.

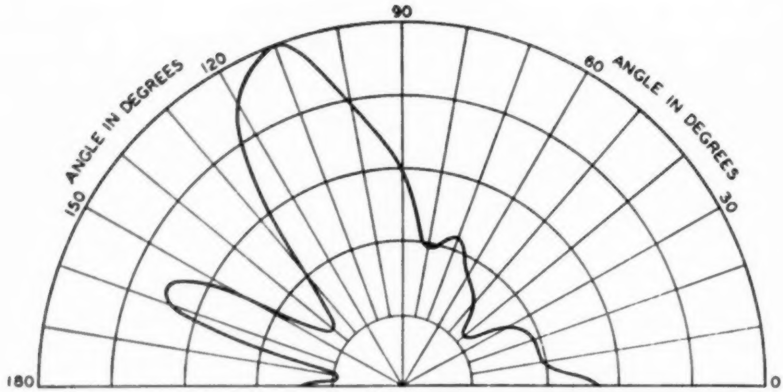

Fig. 3. Variation of intensity with direction of the sound radiated by a violin (660 cps).

lished by Backhaus.[3] The directional characteristics of some of the instruments is one of the chief reasons why the music from an orchestra does not sound the same in all parts of a concert hall. The music which we hear comes to us in part directly and in part indirectly, i.e., after one or more reflections from the walls. Both contribute to the esthetic value of the music. The ratio of the direct to the indirect sound, which has been designated by Hughes[4] as the *acoustic ratio*, is to a first approximation inversely proportional to the product of the reverberation time and the angle through which the sound is radiated.[5] For a steady tone by far the greater part of the intensity at a given point in a hall remote from the source is attributable to the indirect sound. However, inasmuch as many of the tones of a musical selection are of short duration, the direct sound is of great importance; it is this sound alone which enables us to localize the source. So far as this ratio is concerned, a decrease in the radiating angle of a loudspeaker is equivalent to a reduction in the reverberation time of the hall. The effect on the music, however, is not entirely equivalent, for the rate of decay of sound in the room is unaltered by a change in directivity of the source, as this depends only on the reverberation time.

As already pointed out, some of the instruments of the orchestra are quite directive and others are nondirectional. In general, it may be said that the instruments of lower register are less directive than those of higher register. To have each instrument as reproduced by the loudspeaker sound just as the instrument itself would sound in the same hall, the loudspeaker would have to reproduce the music from each instrument with a directivity corresponding to that of the instrument itself. This manifestly is impossible. The best that can be hoped for is a compromise. Let the loudspeaking system be designed so that it is nondirective for the lower frequencies, and at the higher frequencies it will radiate the sound through a larger angle than the most directive of the instruments and through a smaller angle than the least directive. Although this compromise means that the individual instruments will not sound exactly like the originals, it carries with it one advantage: at all the seats in the hall included in the radiating angle and at a given distance from the loudspeaker the music

may be heard to equal advantage, whereas with the orchestra itself the most desirable seats comprise only a certain portion of the hall. The optimum radiating angle is largely a matter of judgment; if it is too small the music will lack the spatial quality experienced at indoor concerts; if it is too large there will be a loss in definition.

There is another respect in which the directivity of the source can greatly affect the tone quality. Most loudspeakers radiate tones of low frequency through a relatively large angle, but as the frequency is increased this angle becomes smaller and smaller. Under this condition the relation between the intensities of the high- and low-frequency tones as received directly will be different for almost all parts of the hall. Hence, even with equalization by electrical networks, the reproduction at best can be good only at a few places in the hall. Therefore, the sound radiated not only should be contained within a certain solid angle, but the radiation throughout this angle should be uniform at all frequencies.

The Loudspeaker

At present two kinds of loudspeakers are in wide commercial use, the direct radiating and the horn types. Each has its merits, but the latter was used in the Philadelphia-Washington experiment because it appears to have definite advantages where such large amounts of power are to be radiated. The horn type can be given the desired directive properties more readily, and higher values of efficiency throughout a wide frequency range are more easily realized. In consideration of the large power requirements, high efficiency is of special importance because it will keep to the lowest possible value the power capacity requirements of the amplifiers and because, with the heating proportional to one minus the efficiency, the danger of burning out the receiving units is reduced.

For efficiently radiating frequencies as low as 40 cycles per second (cps), a horn of large dimensions is required. In order that the apparatus may not become too unwieldly the folded type of horn is preferable, but a large folded horn transmits high-frequency tones very inefficiently. As actually used, therefore, the loudspeaker was constructed in two units: one for the lower and the other for the higher frequencies, an electrical network being used to divide the current into two frequency bands, the point of division being about 300 cps.

The Low-Frequency Horn

When moderate amounts of power are transmitted through a horn the sound waves will suffer very little distortion, but when the power per unit area becomes large, second-order effects, usually neglected in considering waves of small amplitude, must be taken into account. The transmission of waves of large amplitude through an exponential horn has been investigated theoretically by M. Y. Rocard.[6] His investigation shows that if W watts are transmitted through the throat of an exponential horn a second harmonic of intensity RW will be generated, where R is given by the relation

$$R = \frac{(\gamma + 1)^2 f^2 \times 10^7 W}{2\rho c^3 f_0^{\,2} A}, \qquad (1)$$

in which f is the frequency of the fundamental, f_0 the cutoff frequency of the horn, c the velocity of sound, ρ the density of air, and A the area of the throat of the horn, all expressed in cgs units. It may be noted that the intensity of the harmonic increases with the ratio of the frequency to the cutoff frequency of the horn; this is another argument against attempting to cover too wide a range of frequencies with a single horn. In Fig. 1 it is shown that in the region of 200 cps the orchestra gives peak powers of about 10 w. If, therefore, 30 w be set as the limit of power that the horn is to deliver at 200 cps, 32 cps as the cutoff frequency of the horn, and 30 db below

the fundamental be assumed as the limit of tolerance of a second harmonic, from Eq. (1) a throat diameter of about 8 in. is determined.*

If the radiation resistance at the throat of a horn is not to vary appreciably with frequency, the mouth opening must be a substantial fraction of a wavelength. This condition calls for an unusually large horn if frequencies down to 40 cps and below are to be transmitted. However, the effect of variations in radiation resistance on sound output can be kept down to a relatively small value if the receiving unit is properly designed. This will be explained in the next section. The low-frequency horn used in these reproductions has a mouth opening of about 25 sq ft. As computed from well-known formulas[7] for the exponential horn the impedance of this horn with a throat diameter of 8 in. is shown in Fig. 4. These curves were computed under the assumption that the mouth of the horn is surrounded by a plane baffle of infinite extent, a condition closely approximated if the horn rests on a stage floor.

Low-Frequency Receiving Unit

When a moving coil receiving unit, coupled to a horn, is connected to an amplifier having an output resistance equal to $n - 1$ times the damped resistance R of the driving coil, it can easily be shown that the sound power output is

$$P = \frac{\left(\frac{EBLT}{nR}\right)^2 r \times 10^{-9}}{\left[T^2 r + \frac{B^2L^2 \times 10^{-9}}{nR}\right]^2 + [x_d + T^2 x]^2} \text{ watts,} \quad (2)$$

where E is the open circuit voltage of the amplifier, L the length of wire in the receiver coil, T the ratio of the area of the diaphragm to the throat area of the horn, $r + jx$ the throat impedance of the horn, and x_d the mechanical reactance of the diaphragm and coil, the mechanical resistance of which is assumed to be negligibly small. From Fig. 4 it may be seen that the mean value of x increases as the frequency decreases to a value below 40 cps, and that x is smaller than r except at the very lowest frequencies. If, therefore, the stiffness of the diaphragm be adjusted so that x_d is equal to T^2 times the mean value of x at 40 cps, the second term in the denominator may be neglected without much error because it will have but little effect upon the sound output except at the higher frequencies, where the mass reactance of the coil and diaphragm may have to be taken into account.

If minimum variations in sound output are desired for variations in r,

$$\frac{B^2L^2 10^{-9}}{nRT^2} = r_0, \quad (3)$$

where r_0 is equal to the geometric mean value of r, which is approximately equal to $A\rho c$.

If α is the ratio of the resistance at any frequency to the mean value, and if the second term in the denominator is neglected, Eq. (2) becomes

$$P = \frac{E^2}{nR} \frac{\alpha}{(1 + \alpha)^2}. \quad (4)$$

In Fig. 4 it is shown that above 35 cps α has extreme values of 2.75 and 0.36, at which points there will be minimum values in P, but these minimum values will not lie more than 1 db below the maximum values. Hence, if the receiver satisfies the condition of Eq. (3), the extreme variations in the sound output will not exceed 1 db, although the horn resistance varies by a factor of 7.5. Also it may be stated here that when the condition of Eq. (3) is satisfied the horn is terminated at the throat end by a resistance equal to the surge resistance of the horn. Thus Eq. (3) establishes a condition of minimum values in the transient oscillations of the horn.

* Since the original publication of this paper, experimental data have been obtained which indicate a second harmonic generation in horns 6 or more db below the value shown by Rocard's equation.[9]

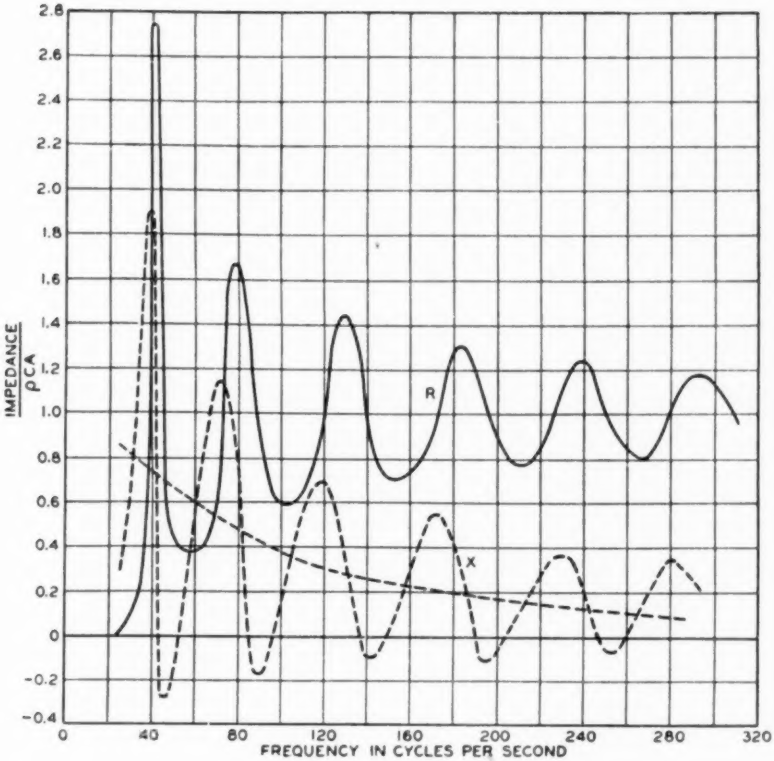

Fig. 4. Radiation resistance and reactance of low-frequency horn.

The mean motional impedance of the loudspeaker is $\frac{B^2L^2 \times 10^{-9}}{T^2r_0}$, which, from Eq. (3), is equal to nR. The condition of Eq. (3) therefore specifies that the efficiency of the loudspeaker shall be $\frac{n}{n+1}$. The maximum power that an amplifier can deliver without introducing harmonics exceeding a specified value is a function of the impedance into which it operates. Therefore, to obtain the maximum acoustic power for a specified harmonic content, the load impedance should have the value for which the product of the loudspeaker efficiency and the power capacity of the amplifier has a maximum value. This optimum value of load impedance for the amplifier and loudspeaker used in the Philadelphia - Washington experiments was found to be about 2.25 times the output impedance of the amplifier; the corresponding value of n then is 2.6 and the required efficiency 72%. For best operating condition a definite value of receiver efficiency thus is specified.

The receiver may be made to satisfy the foregoing conditions regardless of the value of T, the ratio of diaphragm area to throat area. The area of the diaphragm has, however, a definite relation to the maximum power that the receiver can deliver at the low fre-

quencies. The peak power delivered by the receiver is equal to $T^2\alpha r_0\xi^2\omega^2 \times 10^{-7}$ peak watts where ξ is the maximum amplitude of motion of the diaphragm. Figure 1 shows that in the region lying between 40 and 60 cps, peak powers reach a value of from 1 to 2 w. However, the low-frequency tones of an orchestra are undesirably weak and may advantageously be reproduced at a relatively higher level. Therefore it was decided to construct the loudspeaker to be able to deliver 25 w in this region.

As the coil moves out of its normal position in the air gap, the force factor varies. Harmonics thus will be generated, the intensities of which increase with increasing amplitude. A limit to the maximum value of the amplitude ξ thus is set by the harmonic distortion that one is willing to tolerate. In this receiver the maximum value of ξ was taken equal to 0.060 in. Figure 4 shows that $\alpha\omega^2$ has a minimum value at about 50 cycles, where α is equal to about 0.4. These values give a ratio of 4.5 for T.

Inasmuch as $R = \frac{\sigma L^2}{v}$, where σ is the resistivity of the wire used for the coil and v the volume of the coil, from Eq. (3) is obtained

$$B^2v = n\sigma T^2 r_0 10^9. \qquad (5)$$

The first member gives the total magnetic energy that must be set up in the region occupied by the driving coil. This value is fixed by the fact that all factors in the second member are specified. The same performance is obtained with a small coil and high flux density as with a large coil and low flux density, provided B^2v is held fixed, but the coil in any case should not be made so small that it will be incapable of radiating the heat generated within it without danger of overheating, nor so large that the mass reactance of the coil will reduce the efficiency at the higher frequencies.

This receiver unit, when constructed according to the above principles and when connected to an amplifier and a horn in the specified manner, should be capable of delivering power 3 or 4 times that delivered by the orchestra in the frequency region lying between 35 and 400 cps, with an efficiency of about 70%, and with a variation in sound output for a given input power to the amplifier of not more than 1 db throughout this range.

The High-Frequency Horn

It is well known that a tapered horn of the ordinary type has a directivity which varies with frequency. Sound of low frequency is projected through a relatively large angle. As the frequency is increased this angle decreases progressively until, at frequencies for which the wavelength is small compared with the diameter of the mouth opening, the sound beam is confined to a very narrow angle about the axis of the horn.

If we had a spherical source of sound (i.e., a source consisting of a sphere, the surface of which has a radial vibratory motion equal in phase and amplitude at every point of the surface), sound would be radiated uniformly outward in all directions; or, if we had only a portion of a spherical surface over which the motion is radial and uniform, uniform sound radiation still would prevail throughout the solid angle subtended at the center of curvature by this portion of the sphere, provided its dimensions were large compared with the wavelength. Throughout this region the sound would appear to originate at the center of curvature. Hence, for the ideal distribution of a spherical source within a region to be defined by a certain solid angle, it is necessary and sufficient that the radial motion be the same in amplitude and phase over the part of a spherical surface intercepted by the angle and having its center of curvature at the vertex and located at a sufficient distance from the vertex to make its dimensions large compared with the wavelength. If, further, these conditions are satisfied for this surface

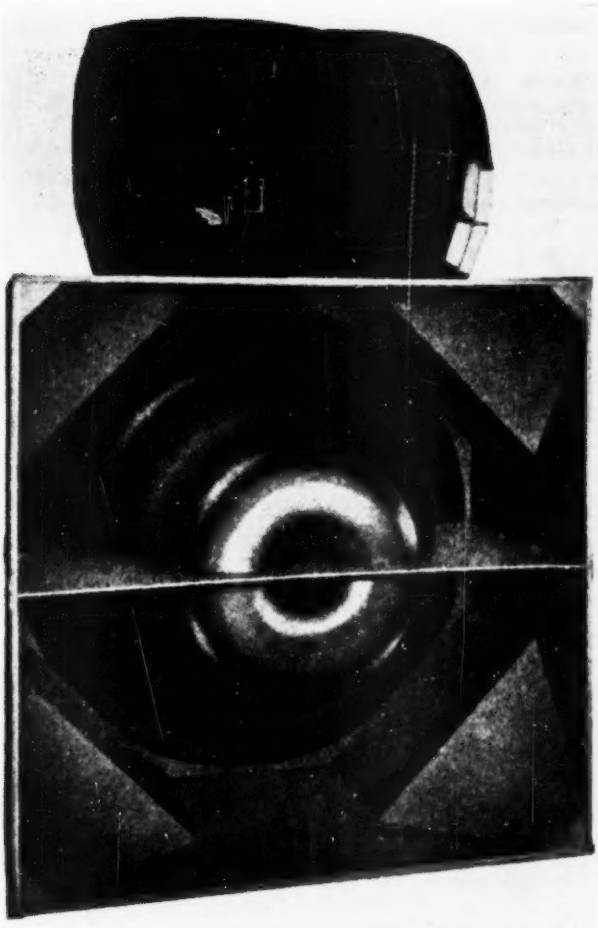

Fig. 5. Special loudspeaker developed for auditory perspective experiment.

at all frequencies, all points lying within the solid angle will receive sound of the same waveform. A horn was designed to meet these requirements for the high-frequency band.

The horn, shown in the upper part of Fig. 5, comprises several separate channels, each of which has substantially an exponential taper. Toward the narrow ends these channels are brought together with their axes parallel, and are terminated into a single tapered tube which at its other end connects to the receiver unit. Sound from the latter is transmitted along the single tube as a plane wave and is divided equally among the

several channels. If the channels have the same taper, the speed of propagation of sound in them is the same. The large ends are so proportioned and placed that the particle motion of the air will be in phase and equal over the mouth of the horn. This design gives a true spherical wavefront at the mouth of the horn at all frequencies for which the transverse dimensions of the mouth opening are a large fraction of a wavelength.

As the frequency is increased, the ratio of wavelength to transverse width of the channels becomes less, and the sound will be confined more and more to the immediate neighborhood of the axis of each channel. The sound then will not be distributed uniformly over the mouth opening of the horn, but each channel will act as an independent horn. To have a true spherical wavefront up to the highest frequencies, the horn would have to be divided into a sufficient number of channels to make the transverse dimension of each channel small compared with the wavelength up to the highest frequencies. If it is desired to transmit up to 15,000 cps, it is not very practical to subdivide the horn to that extent. Both the cost of construction and the losses in the horn would be high if designed to transmit also frequencies as low as 200 cps, as is the case under consideration. However, it is not important that at very high frequencies a spherical wavefront be established over the whole mouth of the horn. For this frequency region it is perfectly satisfactory to have each channel act as an independent horn, provided that the construction of the horn is such that the direction of the sound waves coming from the channels is normal to the spherical wavefront.

The angle through which sound is projected by this horn is about 60°, both in the vertical and in the horizontal direction. For reproducing the orchestra two of these horns, each with a receiving unit, were used. They were arranged so that a horizontal angle of 120° and a vertical angle of 60° were covered. These angular extensions were sufficient to cover most of the seats in the hall with the loudspeaker on the stage. The vertical angle determines to a large extent the ratio of the direct to the indirect sound transmitted to the audience. The vertical angle of 60° was chosen purely on the basis of judgment as to what this ratio should be for the most pleasing results.

The High-Frequency Receiving Unit

In the design of the low-frequency receiver one of the main objectives was to reduce to a minimum the variations in sound transmission resulting from variations in the throat impedance of the horn. However, the high-frequency horn readily can be made of a size such that the throat resistance has relatively small variations within the transmitting region. On the other hand, whereas the diameter of the diaphragm of the low-frequency unit is only a small fraction of the wavelength, that of the high-frequency unit must be several wavelengths at the higher frequencies in order to be capable of generating the desired amount of sound. Unless special provisions are made there will be a loss in efficiency because of differences in phase of the sound passing to the horn from various parts of the diaphragm. The high-frequency receiver therefore was constructed so that the sound generated by the diaphragm passes through several annular channels. There are enough of these channels to make the distance from any part of the diaphragm to the nearest channel a small fraction of a wavelength. These channels are so proportional that the sound waves coming through them have an amplitude and phase relation such that a substantially plane wave is formed at the throat of the horn.

In the appendix it is shown that, for the higher frequencies where the impedance of the horn may be taken as

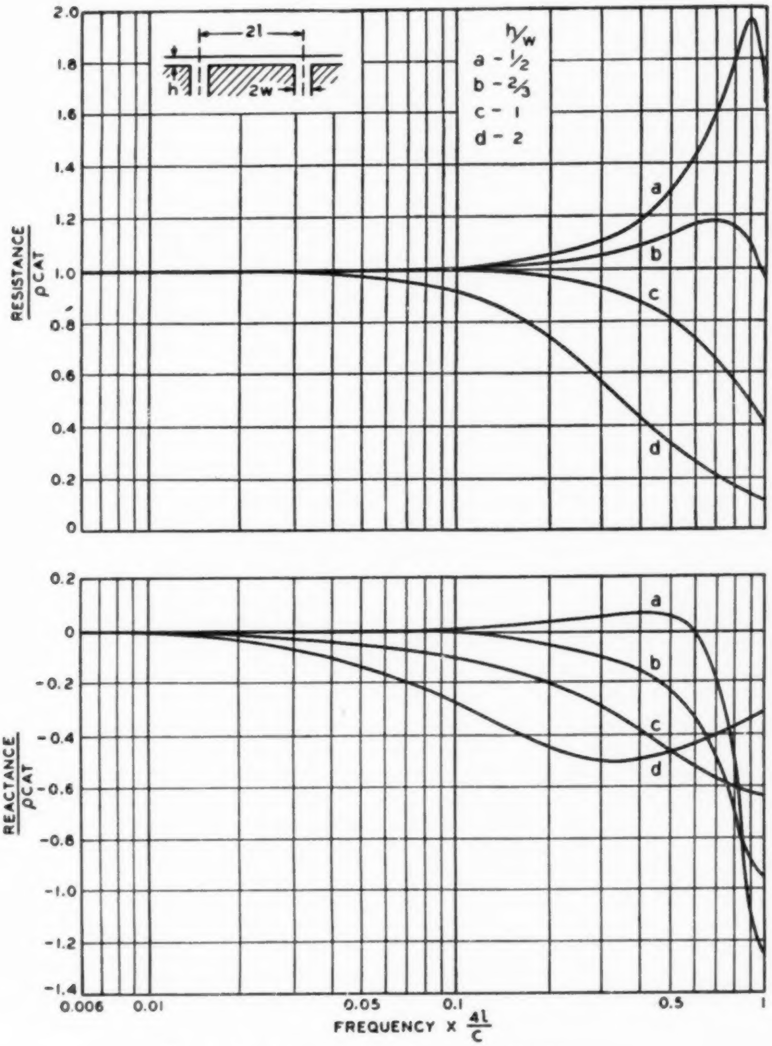

Fig. 6. Load impedance of speaker diaphragm.

equal to ρc times the throat area and for the type of structure adopted, the radiation resistance is equal to

$$\rho c a T^2 \left[\frac{1}{k^2 h^2 T^2 + k^2 l^2 \cot^2 kl} \right] \quad (6)$$

and the reactance

$$-j \frac{\rho c a}{kh} T \left[1 - \frac{1}{kl \cot kl + \left(\frac{hT}{l} \right)^2 kl \tan kl} \right], \quad (7)$$

where a is the area of the throat of the horn, T the ratio of the area of the diaphragm to the throat area, $k = \omega/c$, and the other designations are those indicated in Figure 11. At the lower frequencies the resistance is $T^2 r$ and the reactance $T^2 x$, where r and x are, respectively, the resistance and reactance of the throat of the horn.

Equation (6) shows that at a given frequency, other conditions remaining the same, the radiation resistance will have a maximum value when l is approximately equal to $\pi/2k = c/4f$. In Fig. 6 the resistances as computed from Eq. (6) are plotted as a function of frequency for several values of h/w. It is seen from these curves that the resistance at the higher frequencies is determined very largely by the relation of h/w but is independent of it at the lower frequencies, where it is equal to $\rho c a T^2$. At the lower frequencies where the mechanical impedance of the diaphragm is negligible, the efficiency, as was the case for the low-frequency receiver, depends upon the value of $B^2 v$ where v is the volume of the coil, but at the higher frequencies the efficiency decreases with increasing mass of the coil. It is advantageous, therefore, to keep v small and to make B as large as is practically possible. Values were selected to give the receiver an efficiency of 55% at the lower frequencies. For these conditions the relative sound power output was computed by Eq. (2) on the assumption that the receiver was connected to an amplifier having an output impedance equal to 0.45 times that of the receiver at the lower frequencies. Figure 7 shows the values so obtained. Corresponding values obtained experimentally when the receiver was connected to the horn previously described are shown in Figs. 8 and 9, where the sizes of the rooms in which the values were obtained were, respectively, 5000 and 100,000 cu. ft. Both of these curves differ considerably from the computed curve, particularly as regards loss at high frequencies. The curve of Fig. 8 shows less, and that of Fig. 9 more, loss at high frequencies. The computed curve, however, refers to the total sound output, whereas the measured curves give average values of sound intensity in a certain part of the room, values dependent upon the acoustic characteristics of the room.

The number of high-frequency receivers that must be used for each transmitting channel is governed largely by the amount of power that the system is to deliver before harmonics of an objectionable intensity are introduced. The generation of harmonics in a horn when transmitting waves of large amplitude already has been discussed. Let it suffice here to say that, for a given percentage harmonic distortion, the power that can be transmitted through the horn is proportional to the area of the throat and inversely proportional to the square of the ratio of the frequency to the cutoff frequency.

Inasmuch as the moving coil microphones used for the transmission of music in acoustic perspective have been described previously[5] they will not be discussed here at length. Their frequency-response characteristic as measured in an open sound field for several different angles of incidence of the sound wave on the diaphragm are shown in Fig. 10 where it is seen that the response at the higher frequencies becomes less as the angle of incidence is increased. In general, this is not a

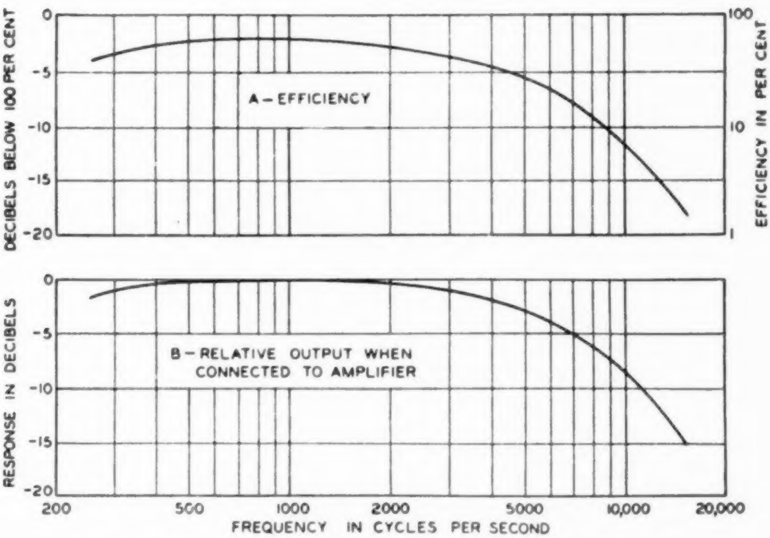

Fig. 7. Relative computed sound output of high-frequency receiver.

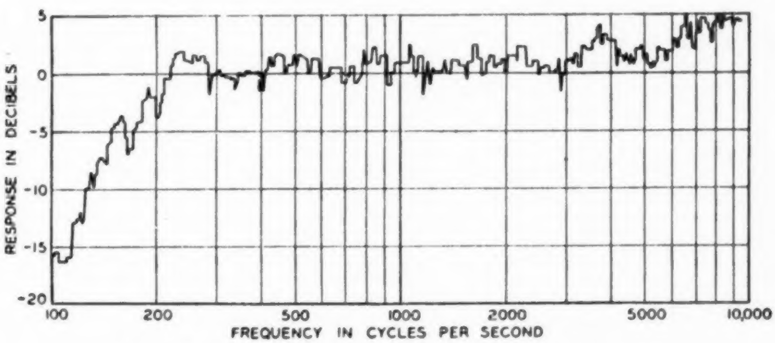

Fig. 8. Output-frequency characteristic of high-frequency receiver as measured in a small room.

desirable property, but with the instruments as used in this experiment the sound observed as coming from each loudspeaker is mainly that which is picked up directly in front of each microphone; sound waves incident at a large angle do not contribute much.

At certain times the sound delivered by the orchestra is of very low intensity. Therefore it is important that the microphones have a sensitivity as great as possible, so that the resistance and amplifier noises may readily be kept down to a relatively low value. At 1000 cps these microphones, without an amplifier, will deliver to a transmission line 0.05 μw when actuated by a sound wave having an intensity of

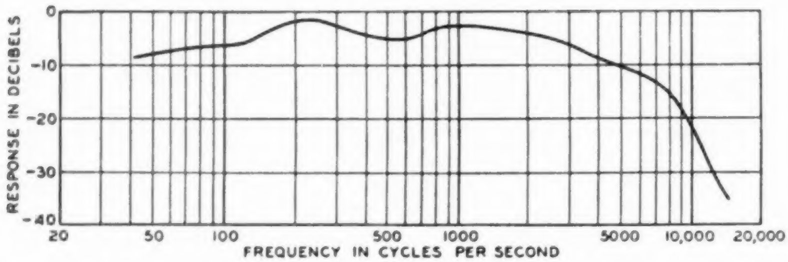

Fig. 9. Output-frequency characteristic of combined low- and high-frequency receivers as measured in a large room.

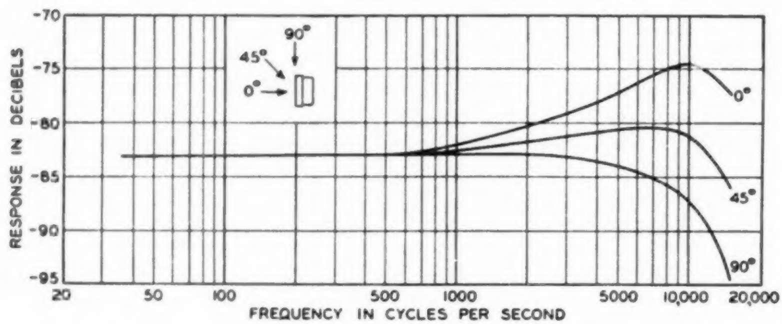

Fig. 10. Output-frequency characteristic of moving coil microphone.

1 μw/sq cm. This sensitivity is believed to be greater than that of microphones of other types having comparable frequency-response characteristics, with the possible exception of the carbon microphone.

APPENDIX

Load Impedance of a Diaphragm Near a Parallel Wall with Slot Openings

First assume a diaphragm and a parallel wall of infinite extent separated by a distance h, and that the wall is slotted by a series of equally spaced openings as shown in Fig. 11. From symmetry it is known that when the diaphragm vibrates there will be no flow perpendicular to the plane of the paper or across the planes indicated by the dotted lines. Therefore only one portion of unit width, such as *abcdef* need be considered. Let the x and y reference axes be located as shown. If the general field equation

$$\frac{\partial^2\varphi}{\partial x^2} + \frac{\partial^2\varphi}{\partial y^2} + k^2\varphi = 0 \qquad (8)$$

is applied when the diaphragm has a normal velocity equal $\xi e^{i\omega t}$ the following boundary conditions are obtained:

When

$$\begin{aligned} x &= 0, \quad \partial\varphi/\partial x = -\xi, \\ x &= h, \quad \partial\varphi/\partial x = 0, \\ y &= 0, \quad \partial\varphi/\partial y = 0, \end{aligned}$$

and when $y = l$, the pressure is equal

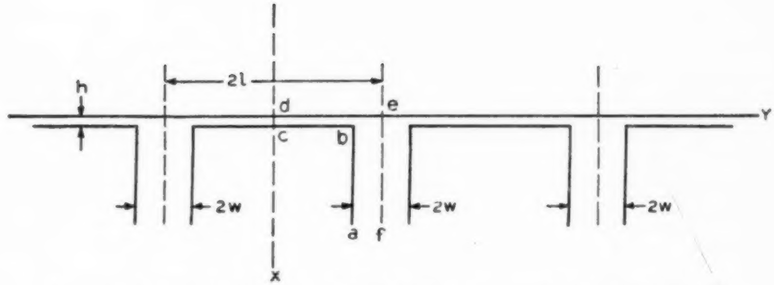

Fig. 11. Schematic diagram of diaphragm and parallel slotted wall of infinite length.

to the product of acoustic impedance and volume velocity or

$$\frac{\rho}{h}\int_0^h \left(\frac{\partial\varphi}{dt}\right)_{y=l} dx = \frac{c\rho}{w}\int_0^h\left(-\frac{\partial\varphi}{\partial y}\right)_{y=l} dx$$

where φ is the velocity potential, $k = \omega/c$, and c is the velocity of sound.

The appropriate solution of Eq. (8) then is

$$\varphi = \frac{\xi}{k}\left[\frac{\cos ky}{kh\left(\cos kl + i\dfrac{h}{w}\sin kl\right)} - \frac{\cos k(x-h)}{\sin kh}\right].$$

The average reacting force per unit area of the diaphragm is

$$\frac{ik\rho c}{l}\int_0^l (\varphi)_{x=0}\, dy.$$

Thus, for the impedance per unit area, which is equal to the force divided by the velocity, is obtained

$$\frac{\rho c l}{w}\left\{\left[\frac{\sin^2 kl}{k^2l^2}\,\frac{1}{\cos^2 kl + \left(\dfrac{h}{w}\right)^2\sin^2 kl}\right] - j\frac{w}{h}\left[\frac{\dfrac{kh\cos kh}{\sin kh}kl - \dfrac{\sin kl\cos kl}{\cos^2 kl + \left(\dfrac{h}{w}\right)^2\sin^2 kl}}{k^2l^2}\right]\right\} = r' + jx'.$$

In all practical types of loudspeakers $kh\cos kh/\sin kh$ would be very nearly equal to 1; then

$$r' = \frac{\rho c l}{w}\left[\frac{1}{k^2l^2\left(\left(\dfrac{h}{w}\right)^2 + \cot^2 kl\right)},\right]$$

$$x' = -\frac{\rho c l}{h}\left[\frac{kl - \dfrac{1}{\cot kl + \left(\dfrac{h}{w}\right)^2\tan kl}}{k^2l^2}\right].$$

If the total area of the diaphragm is A and that of the corresponding channels a, then $A/a = l/w$, approximately, and the total impedance becomes

$$r = \frac{\rho c A^2}{a}\cdot\frac{1}{\left(\dfrac{kh}{a}\right)^2 A^2 + k^2l^2\cot^2 kl},$$

$$x = -j\frac{\rho c A}{kh}\left[1 - \frac{1}{kl\cot kl + \left(\dfrac{h}{l}\dfrac{A}{a}\right)^2 kl\tan kl}\right].$$

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